Volatility Spillovers, Comovements and Contagion in Securitized Real Estate Markets

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ABSTRACT

This paper analyzes the relationships between local and global securitized real estate markets, but also between securitized real estate markets and common stock markets. First, the volatility transmissions across markets are examined using an asymmetric t-BEKK specification of their covariance matrix. Second, correlations from that model and tail dependences estimated using a time-varying copula framework are analyzed in order to assess whether different dynamics underlie the comovements in the whole distribution and those in the tails. Third, we assess market contagion by testing for structural changes in the tail dependences. We use data for the U.S., the U.K. and Australia for the period 1990-2010 as a basis for our analyses. Spillover effects are found to be the largest in the U.S., both domestically and internationally. Further, comovements in tail distributions between markets appear to be quite important. We also document different dynamics between the conditional tail dependences and correlations. Finally, we find evidence of market contagion between the U.S. and the U.K. markets following the subprime crisis.

Keywords: Volatility Spillovers; Comovements; Financial Contagion; Asymmetric BEKK Model; Copulas; Structural Breaks; Real Estate Securities; International Markets; Stocks

JEL classification: G11; G15; C32

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I. INTRODUCTION

Numerous studies have documented the benefits of including real estate in mixed-asset portfolios, both in terms of expected return increase and volatility reduction. An example of such studies is the paper by Hoesli, Lekander and Witkiewicz (2004) who also show the importance of this asset class in implementing an international portfolio strategy. In practice, however, investing in real estate is not unproblematic given, for example, the high unit value and illiquidity of properties. Thus, it is not surprising that the importance of the securitized real estate market has grown substantially during the past decades, with the worldwide market capitalization reaching \$1,159 billion as of July 2010.[1] Indeed, the characteristics of real estate securities overcome many of the drawbacks related to direct real estate. Thus, an understanding of the nature of real estate stocks is crucial for investors seeking to invest in real estate by acquiring real estate stocks.

An important stream of research has developed in this area. Due to the hybrid nature of real estate stocks, many studies have been carried out in order to examine the relationships with stocks, bonds and its underlying asset (i.e., real estate). Clayton and MacKinnon (2003), for instance, show that securitized real estate is mainly linked to the stock market. Other studies have documented that real estate securities have a strong relationship with the direct real estate market only in the case where a long-run analysis is realized (Geltner and Kluger, 1998). Some studies have focused on the factors underlying the return dynamics (Peterson et Hsieh, 1997) and others on those underlying the variance (Stevenson, 2002). The interactions across national markets have also received much interest in the literature (see, for instance, Michayluk, Wilson and Zurbruegg, 2006).

Our paper analyzes the relationships between securitized real estate markets and common stock markets (national analysis), but also between local and global securitized real estate markets (international analysis). Data for the U.S., the U.K. and Australia are used for the period 1990-2010 as the basis for our research. The first part of our investigation is motivated by the fact that real estate stocks are stocks by definition, even though the underlying asset is direct real estate. With the international analysis, we will be able to assess the scope of influence of each of these three national markets on the global market and vice versa. As those markets play an

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[1] *European Public Real Estate Association* (EPRA), *Monthly Statistical Bulletin* of July 2010.

important role in the worldwide economy as well as in real estate markets, a better understanding of their characteristics is therefore warranted.

A wide range of analyses of those inter-linkages is covered in this study. The first objective of this paper is to study the volatility spillover dynamics by means of news impact surfaces (developed by Kroner and Ng, 1998) plotted by using the parameter estimates from an asymmetric t-BEKK (Baba-Engle-Kraft-Kroner) specification of the covariance matrix. This model was preferred to other multivariate GARCH (*Generalized Autoregressive Conditional Heteroscedasticity*) models for three reasons. First, it allows the examination of the volatility spillovers (of interest in our study) which is not the case, for instance, with the popular DCC (*Dynamic Conditional Correlations*) of Engle (2002). Furthermore, the ease of introducing a leverage term[2] expressing the asymmetry in the reaction of the volatility with respect to the sign of the innovation also represents an advantage. Finally, this model has been preferred to the EGARCH (*Exponential Generalized Autoregressive Conditional Heteroscedasticity*) model (Nelson, 1991) for expressing the asymmetry in that it is less sensitive to large shocks and thus yields more efficient results (Engle and Ng, 1993).

The second objective of the paper is to investigate the relationships by focusing only on the extreme events in the series under investigation. Both constant and time-varying tail dependences are calculated by means of the symmetrized Joe-Clayton copula (Patton, 2006). The limits of using a linear approach to model the dependence between random variables (e.g. correlations) have been extensively documented in the literature.[3] Consequently, it is of primary interest to go beyond the linear approach. Dependence measures based on copulas address this issue. Indeed, all the information necessary to describe the dependence structure between random variables is contained in the copula which also captures their nonlinear dependence. Also, copulas do not require elliptically distributed individual variables contrary to the correlations. Moreover, the decomposition of the multivariate distribution into marginal distributions and copulas gives much more flexibility than seeking to find an existing multivariate distribution for fitting random variables.

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[2] The term 'leverage effect' refers to the fact that a firm becomes more highly leveraged when its value diminishes, which raises the stock price volatility since the firm is now riskier (Black, 1976). Another economic theory exists that explains the asymmetric volatility, i.e. the 'volatility feedback' theory based on the existence of time-varying risk premiums. In this paper, we adopt the first definition. For an empirical work testing these two theories, see Bekaert and Wu (2000).

[3] See, for instance, Embrechts, McNeil and Straumann (2002).

Another advantage of copulas is the possibility to obtain information about the joint behavior of the random variables in the tail distribution. This point is of particular interest for financial modeling as extreme events appear to be quite frequent in the financial markets. Another competitive approach to model extreme events is the extreme value theory (EVT), but this theory suffers from two shortcomings. First, it implicitly assumes asymptotic dependence which leads to an overestimation of risks (see Poon, Rockinger and Tawn, 2004). Second, an extreme observation must be defined exogenously creating a certain bias.

For comparison purposes and in order to contribute to the debate of the superiority of a copula approach over a linear correlation approach, conditional correlations are also computed from the BEKK model used in this paper. By confronting the time-varying tail dependences and correlations, differences in their respective evolution across time patterns may be assessed. Thus, those results should have financial implications in terms of asset and risk management. Indeed, depending on the robustness of the results obtained across both analyses, an investor may consider differently his asset allocation.

The third objective of this research is to assess the impact of a crisis (with a focus on the recent financial crisis) on the fundamental relations between markets. In other words, we test for financial contagion according to the definition of Forbes and Rigobon (2002), namely the presence of a significant increase of cross-markets linkages after a shock. We combine the copula theory used in this study with a structural break test developed by Dias and Embrechts (2004) for testing for financial contagion. Utilizing tail dependences for expressing the cross-market linkages is in line with Bae, Karolyi and Stulz (2003) who argue for the importance of extreme events for testing contagion: "The concerns about contagion are generally founded on the presumption that there is something different about extremely bad events that leads to irrational outcomes, excess volatility, and even panics. In the context of stock returns, this means that if panic grips investors as stock returns fall and leads them to ignore economic fundamentals, one would expect large negative returns to be contagious in a way that small negative returns are not."[4] This supports the idea that analyzing the shifts in correlations as a manner for evaluating the evidence of contagion is of limited scope.

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[4] Bae, Karolyi and Stulz (2003, p. 718-719).

Besides the fact that we do not work with correlations, we also use a methodology where there is no discretion in defining what "usual" is as would be the case with EVT. In this respect, we overcome a drawback of an EVT-based approach. Another way to work in this spirit would be to assess the connections between markets after having controlled for economic fundamentals. However, contagion being associated to high frequency data, such type of data are not available for macroeconomic variables (Moser, 2003). Our methodology does not require macroeconomic data. Finally, the time of occurrence of a break is endogenously defined by the structural break test of Dias and Embrechts (2004). Dungey and Zhumabekova (2001) show that the size of crisis and non crisis periods is central in the analysis of contagion; as we analyze the changes in the tail dependences between the pre-crisis and the post-crisis periods, this point is crucial in our case. Therefore, our approach is particularly appealing for testing financial contagion.

Since the U.S. market is recognized as having been the center of the financial crisis, this part of the analysis only considers those pairs which include the U.S. Thus, our study is carried out on the following pairs: U.S. and U.K. securitized real estate markets, U.S. and Australian securitized real estate markets, and finally U.S. equity and securitized real estate markets. The analysis of this latter pair is motivated by the intuition that the contagion may also occur across different sectors of a given country. This was the case e.g. during the Asian flu; the real estate market plummeted and then affected the rest of the financial sector (see Kallberg, Liu and Pasquariello, 2003).

Our study yields a number of interesting results. First, for the national analyses, we find the strongest volatility spillovers and asymmetry in the U.S.; the two others countries exhibiting more mitigated relations and asymmetry. As regards the international analyses, it appears that the three local markets influence more the volatility of the global market than the reverse, arguing for the importance of those markets. Except to some extent for Australia, we find that those interactions are not driven by exchange rate factors. Second, the extreme joint behavior of the series analyzed shows rather high tail dependence coefficients in both the national and international analyses. In general, we also document an asymmetric feature underlying these extreme comovements. Those results are supported by the time-varying tail dependences that exhibit quite high levels. We also find that the conditional tail dependences remain rather stable over our sample period for each

pair studied. The conditional correlations do not follow the same evolution, especially since 2005. Finally, concerning financial contagion, we observe such a phenomenon only between the U.S. and the U.K. following the subprime crisis and not the recent financial crisis. The other pairs do not show similar results. However, two structural breaks are found in the relationships between U.S. equity and securitized real estate markets, but their time of occurrence does not correspond to any obvious crisis.

This paper contributes to the existing literature in three ways. First, we introduce a methodology for testing financial contagion which has never been used for this purpose. As mentioned above, this methodology has many advantages. We include in our analysis the recent global financial and real estate crises which have received very little attention from a financial contagion point of view. Second, no paper has covered as thoroughly the different aspects of the interactions between assets or markets (i.e., volatility spillovers, extreme joint behavior, and financial contagion). As a consequence, little has been said about the confrontation of the results from the analysis of extreme returns with those from the analysis of the entire distribution. Finally, few studies have sought to investigate whether there are some mutual influences between the global securitized real estate market and a local market. Indeed, research to date has mainly focused on the relationships between two national markets. We contribute therefore to the debate on whether assets are globally priced.

The paper is organized as follows. Section II contains a literature review, while the next section presents the data as well as some descriptive statistics. The two following sections explain the methods used in this study and the empirical results, respectively. A final section contains some concluding remarks.

II. LITERATURE REVIEW

The interactions between various assets or markets have been the subject of much attention in recent years. Indeed, for portfolio diversification purposes, this field of study has interested both academics and practitioners. The very first papers focused on stock market inter-linkages at an international level analyzing the return and volatility dynamics underlying the financial markets. Much attention has been given

to the volatility spillovers. These studies include Hamao, Masulis and Ng (1990), Bae and Karolyi (1994) and Karolyi (1995).[5] An ARCH (*Autoregressive Conditional Heteroscedasticity*) modeling framework for short-run analysis is used to characterize the volatility transmission. In most cases, there is significant evidence of interdependence. Moreover, Bae and Karolyi (1994) show for the U.S. and Japan that bad news affect more strongly the volatility transmission than good news. Evidence of non constant correlations across time, another important characteristic of the international market links, is shown by Longin and Solnik (1995). For more recent research on international stock market interactions, see Baele (2005) who shows increasing volatility spillover effects in the Western European markets; Bekaert, Hodrick and Zhang (2009), using risk-based factor models, confirm these results, while finding mixed evidence of interdependence in other regions.

Given the benefits of being exposed to real estate in a portfolio context, but also the drawbacks of investing in direct real estate, real estate securities have been the focus of much research. Being stocks by definition, real estate stocks are obviously influenced by the broader stock market; such influences having been analyzed in several papers. Using multi-factor asset pricing techniques, Ling and Naranjo (1999) find that the real estate investment trusts (REITs) market is integrated with that of stocks; however, no such evidence is found in relation to the direct real estate market. Studies such as Stevenson (2002) and Cotter and Stevenson (2006) also report strong relationships based on volatility transmission tests conducted with different GARCH models or time-varying correlations. In the first paper, several univariate GARCH models with exogenous variables are used. A particular link with the small cap and value stocks is found. This result is intuitively appealing as real estate stocks have similar characteristics to these assets. In the second paper, the authors conclude that the frequency of the data might have an influence on the empirical results. Using a symmetric BEKK[6] model and daily returns, they find that the stocks of large firms impact more strongly the real estate security market than when monthly returns are used. A more recent paper by Yang, Zhou and Leung (2010) document the strong asymmetric correlations between the REITs and the S&P500 during the period 1998-2008 by means of a multivariate asymmetric

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[5] For further studies on volatility spillovers involving the equity market, see Karolyi and Stulz (1996), King, Sentana and Wadhwani (1994), and Susmel and Engle (1994).

[6] Miao, Ramchander and Simpson (2011), and Wong, Chau and Yiu (2007) also use the symmetric BEKK model for volatility spillover purposes, but analyze the housing markets, and the real estate spot and forward markets, respectively.

generalized dynamic conditional correlation GARCH model. To some extent, we can thus conclude that the broader stock market impacts the real estate security market.

Investors increasingly seek to go international on real estate markets. Thus, many studies have been carried out in this field. The aim of these studies is to assess the possibilities that a common international factor exists between the different domestic property stock markets. Michayluk, Wilson and Zurbruegg (2006) look at the asymmetric volatility transmission, the correlations and the return dynamics between the U.S. and the U.K. real estate security markets. Using the ADC (*Asymmetric Dynamic Covariance*) model proposed by Kroner and Ng (1998), they find that the two markets are linked when synchronously priced data are examined and that there exists an asymmetric effect on both the volatilities and the correlations between the markets. Using a multivariate dynamic conditional correlation model (Engle, 2002), Liow et al. (2009) study the international linkages between listed real estate markets (across countries and across regions). They detect higher correlations amongst the stock markets than amongst the securitized real estate markets. Furthermore, a strong and positive connection is found between the conditional correlations and their volatilities. Finally, the international property stock market correlations are linked to those of the broader stock market.

Liow and Newell (2011), using an asymmetric BEKK model, report evidence of volatility transmissions within Greater China and between Greater China and the U.S. By means of regression techniques, they also evaluate the impact of the recent financial turmoil on the correlations and find a significant increase. Using eight Asian markets, Liow (2012) analyzes the dynamics underlying the international correlations between stocks and securitized real estate at a local, regional and global level by means of an asymmetric dynamic conditional correlation model (Cappiello, Engle and Sheppard, 2006). He also looks at changes in correlation and covariance's composition (volatilities and correlations) following the recent financial crisis. He finds some time-varying and asymmetric links as well as the important role played by the crisis. Taking into account the possibility to have regime-dependent returns (using Bai and Perron's (2003) methodology) and volatilities (using a multivariate regime-dependent asymmetric dynamic covariance methodology), Liow, Chen and Liu (2009) detect mean and volatility interdependences (across different regimes) in five major securitized real estate markets. Going beyond a GARCH framework, Yunus (2009), basing her analysis on cointegration tests, and Zhou (2010), adopting a

wavelet analysis, also study the comovements across international markets. The former author documents increasing common behavior, whereas the latter does not find such a pattern.

The analysis of extreme events appearing in financial series is a stream of research becoming increasingly popular. For instance, Longin and Solnik (2001) estimate the extreme correlations of international equity markets using the EVT and find that the correlations increase in bear markets. Again employing the EVT, Liow (2008) calculates the value-at-risk of property stocks and concludes that these assets present important features of extreme risks. However, much emphasis has been placed on analyzing such events using a methodology based on copulas. For instance, Jondeau and Rockinger (2006) use copulas to model international stock markets. Patton (2006) pioneered the inclusion of time-variation in copulas by developing conditional asymmetric tail dependences. He applies this extension of the theory of copulas to the Forex market and finds evidence of asymmetric tail dependence. As regards the real estate field, some studies have used a copula framework for analyzing the extreme joint behavior of the real estate markets. Knight, Lizieri and Satchell (2005) choose the constant symmetrized Joe-Clayton copula for examining the relationships between real estate and stocks for both the U.K. and global markets. Generally, strong tail dependence is shown by the authors, particularly in the negative tail. Employing the same copula, but allowing the parameters of the copula to be time-varying (Patton, 2006), Gao and Zhou (2010) study the conditional tail dependences of six major global markets (U.S., U.K., Japan, Australia, Hong Kong and Singapore). They conclude that the levels of the tail dependences vary amongst the different pairs created. Within the same methodological framework, Goorah (2007) discusses the limitations of the linear correlations by estimating tail dependences between the U.S. and the U.K property stock markets. Finally, Simon and Ng (2009) examine the impact of the real estate/mortgage crisis on the linkages between REITs and equities. Based on the results coming from a flexible mixed-copula approach, they observe that REITs have an important ability to protect against numerous downturns of the stock market in the U.S.

The impact of a crisis on financial markets is of paramount interest for both investors and policymakers. This area of research has also been widely documented by researchers. However, the paper by Forbes and Rigobon (2002) represents the cornerstone of research in this area because they question the reality of contagion by

giving a more precise definition to this term: for observing contagion, we must find a significant increase of cross-market linkages after a shock to one country. The first papers trying to implement empirically such a definition base their measure of cross-market linkages on correlations via time series models; for instance, Caporale, Cipollini and Spagnolo (2005) and Chiang, Jeon and Li (2007). Both sets of authors find evidence of contagion in the Asian markets after the crisis of 1997. Another stream for testing for financial contagion involves the use of extreme situations. The idea was brought forward by Bae, Karolyi and Stulz (2003), who estimate the "coincidence of extreme return shocks across countries". Using a multinomial logistic regression model, they detect contagion phenomena in the emerging markets during the 1990s. In line with this paper, Rodriguez (2007), using data from the markets influenced by the Asian crisis or the Mexican crisis, investigates the structural breaks in the tail dependences modeling the inter-linkages between the markets by implementing a switching-parameter copulas. Only the Asian markets experience an increase in their tail dependence. Financial contagion in Asia is also found by Bekaert, Harvey and Ng (2005). To do so, the authors develop a two-factor asset pricing model and look at the correlations in the residuals after controlling for the local and foreign shocks.

The real estate markets have also been the subject of financial contagion analyses. Kallberg, Liu and Pasquariello (2002) examine the regime shifts in the structural relations between the equity and real estate security markets in eight developing Far Eastern countries. The methodology of Bai, Lumsdaine and Stock (1998) is used in this paper. They find regime shifts appearing during the crisis quite synchronously through the countries analyzed (evidence of contagion). They also document that real estate did not cause the crisis. By means of a multivariate cointegrated system allowing for structural breaks (endogenously determined), Gerlach, Wilson and Zurbruegg (2006) also study the impact of the Asian crisis on the links between real estate security markets in the Asian-Pacific region. Their results reveal a structural break during the crisis. The transmission of the Asian crisis across national real estate markets is also examined by Bond, Dungey and Fry (2006). Trough a multivariate latent factor framework, reduced diversification opportunities after the crash are found by the authors.

III. Data and Preliminary Statistics

The data related to real estate securities are sourced from the EPRA/NAREIT[7] database and those related to equities from Datastream International. They are all weekly closing prices of national or global indices which represent the world securitized real estate market covering the period December 28, 1989 to May 28, 2010, thus yielding approximately 1,100 observations. If a market was closed one trading day because of a holiday, the price observation of this day has been replaced by that of the previous trading day. Three national markets have been chosen, i.e., those of the U.S., the U.K. and Australia.

The issues that emerge when working with global indices related to the discrepancies in the opening hours of stock exchanges around the world are eliminated by using weekly returns. Indeed, a study by Martens and Poon (2001) shows that the daily stock market correlations are affected by the use of non-synchronous data. Moreover, the fact that the trading volume of the property stocks is much smaller than that of other assets, one might expect longer delays in the reactions to foreign news (Michayluk, Wilson and Zurbruegg, 2006). Lack of liquidity in a market leads to less and slower information flows across markets. Besides, the day-of-the-week effect is also addressed by this means. Thus, the use of weekly returns is particularly appealing.

The global indices are expressed in the currency of the country under analysis leading to an analysis under the perspective of an investor unhedged against the currency risk. In order to avoid biases in the empirical results, the domestic market studied is excluded from the world index. However, such an index is not available for Australia in the EPRA/NAREIT database. Given the limited size of the Australian securitized real estate market ($69 billion as of July 2010 representing about 6% of the world market), this should not have a noticeable influence on the results. Logarithmic returns are calculated from the different indices for the analyses in this paper.

Table 1 provides descriptive statistics for real estate stock returns in the three countries analyzed. The four moments are reported first. Given that we use weekly data, the mean return is close to zero, while the standard deviations are comprised

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[7] *European Public Real Estate Association/National Association of Real Estate Investment Trusts.*

between 2.50% and 3.10%. U.S. real estate stocks are the riskiest and offer the highest returns as well. All the return series are leptokurtic and negatively skewed, inconsistent with a normal distribution. In addition, the Jarque-Bera statistics reject the null hypothesis of normality at the 1% significance level.

[Insert Table 1 about here]

An augmented Dickey-Fuller (ADF) test with trend and four lags was performed in order to check for stationarity. The unit-root null hypothesis is rejected (the series are stationary) and thus the returns do not need to be transformed before the models' estimations. The raw and the squared returns are characterized by the presence of strong autocorrelations (Ljung-Box Q test). The conditional heteroskedasticity is also, more formally, confirmed by the Lagrange multiplier test of Engle (1982) which detects the presence of ARCH effects. Similar results prevail with the other data.[8] In short, the statistical distribution characteristics of our series support the usage of ARCH models.

As a first step in the analysis of the interdependences between the markets, linear correlations are evaluated. Table 2 indicates high correlations between stocks and securitized real estate (figures of about 0.60). Lower levels are found in the international context, with correlation coefficients of about 0.50 for the U.S. and U.K., whereas the coefficient does not exceed 0.40 for Australia.

[Insert Table 2 about here]

IV. METHODS

IV.I MULTIVARIATE GARCH MODEL

The homoskedasticity assumption of the error term variance made in the traditional econometric models is rather strong when financial time series are used. For instance, the clustering phenomenon present in the financial data volatility is an example which refutes this assumption. In order to consider the clustering effect, Engle

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[8] The descriptive statistics for the other indices (stocks and global real estate stocks) are available upon request.

(1982) established the ARCH model. The conditional variance is expressed as a linear function of the squared past innovations. Bollersev (1986) generalized the ARCH model (GARCH), adding the past conditional variance as an explanatory variable, for parsimony purposes.

As we are interested in the analysis of volatility transmission between different markets, a multivariate GARCH setup is necessary. We will consider that the variance-covariance matrix follows a GARCH process instead of the variance as is the case in the univariate framework. Different specifications of the covariance matrix have been proposed, but only the Baba-Engle-Kraft-Kroner (BEKK) model defined in Engle and Kroner (1995) which is a restrictive version of the original VEC model (Bollersev, Engle and Wolldridge, 1988) has been chosen to analyze the volatility spillovers.

This specification has two main advantages. First, it reduces considerably the number of parameters to be estimated especially when the dimensions of the model are large. Second, it ensures the positive definiteness of the variance-covariance matrix due to the last three terms of the equation which are expressed in quadratic forms (see equation (2)), provided that the constant term is positive definite. This specification assumes that the covariance matrix is determined by lagged shocks (ARCH effect) and its own past values (GARCH effect).

According to the model proposed by Glosten, Jagannathan and Runkle (1993) in a univariate framework, a leverage term is added to the original BEKK expression of the conditional covariance matrix. Thus, we obtain an asymmetric t-BEKK specification of the variance-covariance matrix. Each variable in the model is considered with a lag of one and the mean equation is modeled as a vector autoregressive process of order one (VAR(1)), due to the presence of autocorrelation in the return series. The choice of the number of lags has been motivated by the financial literature which shows that a GARCH (1,1) fits particularly well financial time series. For ease of interpretation purposes, a series of bivariate models are estimated. Indeed, larger dimensions would lead to some difficulties in isolating the different effects. Thus, the asymmetric t-BEKK specification of the variance-covariance matrix is characterized by the following equation:

$$R_t = K + DR_{t-1} + \varepsilon_t \tag{1}$$

where $R_t = \begin{bmatrix} r_{1t} \\ r_{2t} \end{bmatrix}$, $K = \begin{bmatrix} k_1 \\ k_2 \end{bmatrix}$, $D = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}$, $\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}$

and where $\varepsilon_t = \Sigma_t^{1/2} z_t$, with $z_t \sim$ *i.i.d. Student-t(v)*

thus $\varepsilon_t | \Phi_{t-1} \sim$ *Student-t* $(0, \Sigma_t, v)$

$$\Sigma_t = CC' + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'\Sigma_{t-1}B + N'\Psi_{t-1}\Psi'_{t-1}N \qquad (2)$$

where $C = \begin{bmatrix} c_{11} & 0 \\ c_{12} & c_{22} \end{bmatrix}$, $A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$, $B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$, $N = \begin{bmatrix} n_{11} & n_{12} \\ n_{21} & n_{22} \end{bmatrix}$,

where A, B and N are 2 x 2 parameter matrices and C a lower triangular matrix of constant terms (2 x 2). The error term is represented by ε_t. Equations (1) and (2) represent the mean equation and the asymmetric t-BEKK specification of the time-varying covariance matrix, respectively. The asymmetry term is expressed by the last part in equation (2) where $\Psi_t = \min(0, \varepsilon_t)$. Thus, we will have a relation between negative innovations and the variance-covariance matrix.

Concerning the analysis of volatility spillovers, the parameters with the subscripts '12' or '21' represent the cross market effects, whereas the subscripts '11' or '22' represent the 'own market' effects. However, due to the quadratic form of the asymmetric t-BEKK parameterization, the volatility spillovers are impossible to trace properly. To overcome this issue, we do not comment the parameter estimates and instead use news impact surfaces (three-dimensional graph), a methodology proposed by Kroner and Ng (1998). Holding information at time t-1 constant by setting Σ at its unconditional mean value and treating the innovations (in our bivariate case, from the two series) as a collection of news arriving to a market (Engle and Ng, 1993), the news impact surfaces (NIS) for the conditional second moments are expressed by means of the following function (over the range $\varepsilon_{i,t} = [-4, 4]$):

$$\sigma_{ij,t} = \sigma_{ij}\left(\varepsilon_{i,t-1}, \varepsilon_{j,t-1}; \Phi_{t-1} = \Phi\right) \qquad (3)$$

Under the assumption that the residuals ε_t follow a bivariate Student's t distribution with mean zero, covariance matrix Σ_t conditional to the information available until t-1 (Φ_{t-1}) and degrees of freedom ν ($2<\nu<\infty$), we perform a quasi-maximum likelihood estimation.[9] The aim of this estimation is to find values for the parameters θ which maximize the following log-likelihood function:

$$L(\theta) = \sum_{t=1}^{T} \ln\left[\frac{\Gamma(1+\nu/2)}{\pi(\nu-2)\Gamma(\nu/2)} \left(1 + \frac{\varepsilon_t' \Sigma_t^{-1} \varepsilon_t}{\nu-2}\right)^{-(\nu+2)/2} \right] - \sum_{t=1}^{T} \frac{\ln(|\Sigma_t|)}{2} \tag{4}$$

where $\Gamma(.)$ is the gamma function and T is the length of the time series observed. The real joint distribution of the innovations does not necessarily follow a bivariate Student's t distribution, which leads to refer to this methodology as quasi-maximum. However, in order to obtain consistent results it is crucial to use the approach of Bollersev and Wooldridge (1992) to compute robust standard errors and thus to correct the initial misspecification of the density function.

Based on the estimates above, conditional correlations are calculated from the T variance-covariance matrices. The intuition is that correlations are not constant across time as it has been shown by Longin and Solnik (1995) in an international context. In addition, we can observe the evolution of the levels of correlations during our study period and compare them to the time-varying tail dependences (see next section).

IV.II COPULAS

An appropriate modeling of the relationships between markets is of particular interest for an investor who wants to reduce his exposition to risk. Evaluating the dependence between extreme events is also a useful tool for risk management purposes. Thus, an obvious candidate for such an analysis is the copula framework. Simply speaking, copulas are "functions that join or couple multivariate distribution functions to their one-dimensional marginal distribution functions" (Nelsen, 2006).

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[9] The Student's t distribution partially captures the leptokurtosis of the innovations. Besides, the BEKK model coupled with a bivariate Student's t distribution represents one of the most flexible multivariate models available (Ang and Bekaert, 2002).

COPULA DEFINITION

Consider two random variables (X, Y) with respective marginal distribution functions $F_x(x)$ and $F_y(y)$ and their joint distribution $F_{xy}(x, y)$. Sklar (1959) states that there exists a function C called copula which joins the marginal distributions:

$$F_{xy}(x, y) = C(F_x(x), F_y(y)) \qquad (5)$$

Then, if we set $u = F_x(x)$, $v = F_y(y)$ with $0 \leq u \leq 1$, $0 \leq v \leq 1$ where both are uniformly distributed, we obtain a function $C(u,v)$ defined on a unit rectangle. C covers all possible bivariate distribution functions. In sum, a copula describes the dependence structure existing between two random variables. The estimation procedure requires two stages (called Inference Function for Margins; for further details, see Joe and Xu, 1996) and a semi-parametric approach is used. First, the marginal distributions for the univariate variables are constructed and estimated nonparametrically. Second, the parameters of the copula are estimated by a parametric approach.

MARGINAL DISTRIBUTIONS

In keeping with the financial literature and the discussion contained in section III, first we filter the return series by an AR(1)-GJR-t-GARCH(1,1).[10] As mentioned in the multivariate framework, the GJR-GARCH model was proposed by Glosten, Jagannathan and Runkle (1993) and has the following form:

$$r_t = c + \beta r_{t-1} + \varepsilon_t \qquad (6)$$

$$\varepsilon_t = \sqrt{\sigma_t^2} z_t \text{, with } z_t \sim i.i.d. \text{ Student-t(v)}$$

$$\varepsilon_t | \Phi_{t-1} \sim \text{ Student-t } (0, \sigma_t^2, v)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2 + \varphi I_{\varepsilon_{t-i<0}} \varepsilon_{t-1}^2 \qquad (7)$$

where $I_{\varepsilon_{t-i<0}}$ is a binary variable which takes the value of one if the error term is negative, zero otherwise. Second, we estimate the marginal distributions from the

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[10] The results of this estimation are not reported in this paper. They can be obtained upon request.

residuals obtained in the first step nonparametrically by an empirical cumulative distribution function:

$$\hat{F}_j(x_j) = \frac{1}{T}\sum_{t=1}^{T} I_{x_j^t < x_j} \tag{8}$$

where $I_{x_j^t < x_j}$ is the indicator function which takes the value of one if the argument is true, zero otherwise. The advantage of this approach is that it avoids any misspecification of the marginal distributions which might have an impact on the estimation of the parameters (Dulguerov, 2009).

COPULA FUNCTION AND TAIL DEPENDENCE

As the asymmetry is of interest in this study, the choice of a copula considering this aspect is crucial and represents a noticeable advantage. This is rather intuitive as it has been well documented in the literature (Longin and Solnik, 2001) that financial returns are more strongly linked in the lower tail distribution than in the upper tail. In order to model asymmetric tail dependence, the symmetrized Joe-Clayton (SJC) copula proposed by Patton (2006) has been employed which is a modification of the Joe-Clayton (JC) copula of Joe (1997). This latter is expressed as follows:

$$C_{JC}(u,v|\tau^U,\tau^L) = 1 - (1 - \{[1-(1-u)^\kappa]^{-\gamma} + [1-(1-v)^\kappa]^{-\gamma} - 1\}^{-1/\gamma})^{1/\kappa} \tag{9}$$

$$\text{where} \quad \kappa = 1/\log_2(2-\tau^U)$$

$$\gamma = -1/\log_2(\tau^L)$$

$$\text{and} \quad \tau^U \in (0,1), \quad \tau^L \in (0,1)$$

τ^L and τ^U are the two parameters of the JC copula and represent the lower and upper tail dependences, respectively. The first measure of dependence is defined as:

$$\tau^L = \lim_{q\to 0} P(U \le q|V \le q) = \lim_{q\to 0} P(V \le q|U \le q) = \lim_{q\to 0}\frac{C(q,q)}{q} \tag{10}$$

where $U = F_x(x)$ and $V = F_y(y)$. There is a lower tail dependence if the previous limit exists and $\tau^L \in (0, 1]$. $\tau^L = 0$ indicates lower tail independence. Similarly, the upper tail dependence is defined as:

$$\tau^U = \lim_{\delta \to 1} P(U > \delta | V > \delta) = \lim_{\delta \to 1} P(V > \delta | U > \delta) = \lim_{\delta \to 1} \frac{1 - 2\delta + C(\delta, \delta)}{1 - \delta} \qquad (11)$$

There is an upper tail dependence if the previous limit exists and $\tau^U \in (0, 1]$. $\tau^U = 0$ indicates upper tail independence. Finally, we will have tail symmetry (asymmetry) if $\tau^L = \tau^U$ ($\tau^L \neq \tau^U$).

The SJC copula has been preferred to the JC copula because of the greater accuracy of the former concerning the special case of symmetry (Patton, 2006). Another advantage of the SJC copula is that it gives both lower and upper tail dependence with certain flexibility for the dependence structure. However, the SJC copula has some parsimony issues compared to other more restrictive copulas (i.e., normal and t copulas), but the advantages dominate this drawback.

The SJC copula is characterized by the following formula:

$$C_{SJC}(u,v | \tau^U, \tau^L) = 0.5 \cdot (C_{JC}(u,v | \tau^U, \tau^L) + C_{JC}(1-u, 1-v | \tau^U, \tau^L) + u + v - 1) \qquad (12)$$

In a reduced form, we obtain the following general expression:

$$\hat{F}(x,y | \tau^U, \tau^L) = C_{SJC}(\hat{F}_x(x), \hat{F}_y(y); \tau^U, \tau^L) \qquad (13)$$

The copula parameters τ^L and τ^U of equation (13) are estimated by the maximum likelihood method. The sum of the logarithm of the density function of the copula is maximized given the estimated parameters for the marginal models.

In the previous models, the tail dependences were constant across time (constant SJC copula). Similarly to the correlations, it is quite abusive to assume that these measures of dependence are constant. In order to capture their evolution, a time-varying copula is used in a second analysis. Patton (2006) established a time-varying SJC

copula where the evolution across time of τ^L and τ^U is expressed by the following two equations[11]:

$$\tau_t^L = \Lambda\left(\omega_L + \beta_L \tau_{t-1}^L + \alpha_L \cdot \frac{1}{10} \sum_{j=1}^{10} \left| u_{t-j} - v_{t-j} \right| \right) \tag{14}$$

$$\tau_t^U = \Lambda\left(\omega_U + \beta_U \tau_{t-1}^U + \alpha_U \cdot \frac{1}{10} \sum_{j=1}^{10} \left| u_{t-j} - v_{t-j} \right| \right) \tag{15}$$

where $\Lambda(x) \equiv (1 + e^{-x})^{-1}$ is the logistic transformation. This transformation constraints the tail dependences to stay in (0, 1) during all the period. For further details on the development of this methodology, see Patton (2006).

Thus, two analyses of the extreme return relationships are performed in this paper; one with constant tail dependences and another one with time-varying tail dependences.

IV.III STRUCTURAL BREAK TEST IN COPULA MODELS

The methodology presented in this section is utilized in order to test for financial contagion across markets. The definition in the influential paper by Forbes and Rigobon (2002) is utilized to assess the existence of contagion across markets; we test for an increase of the inter-linkages after a shock. Our aim in this section is to analyze whether we find structural breaks in the dependence structure between two markets around financial stressful times, with a focus on the recent financial crisis. Obviously, other important events might affect the dependence structure. The copula approach presented in the previous section is used for modeling the dependence. This is in accordance with the idea by Bae, Karolyi and Stulz (2003) who pointed out the importance of extreme situations for assessing the contagion phenomenon. Thus, we go further than the conventional approach based on structural shifts in correlations.

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[11] The parameters of equations (14) and (15) are not reported in this paper. They can be obtained upon request.

The structural break test developed by Dias and Embrechts (2004) detecting the presence of a breakpoint in the dependence parameter of a static copula is used in this paper. This test appears appropriate for two main reasons. First, it involves the use of copulas which are of interest in our research because of their accuracy in modeling the dependence structure. Second, the time of occurrence of a structural break is not chosen exogenously but given directly by the method. For contagion test purposes, this point is paramount as it has been shown by Dungey and Zhumabekova (2001) that the size of crisis and non-crisis periods can affect significantly the contagion conclusions.

Suppose $U_1, U_2, ..., U_T$ are a sequence of independent random vectors in $[0, 1]^d$ with univariate uniformly distributed margins and copulas $C(u; \theta_1, \eta_1)$, $C(u; \theta_2, \eta_2)$, …, $C(u; \theta_T, \eta_T)$; θ_i are the parameters of the copula function, whereas η_i are the parameters of the margins treated as nuisance parameters and set as constant. The null hypothesis of no structural break in the copula parameters is as follows:

$$H_0 : \theta_1 = \theta_2 = ... = \theta_T \text{ and } \eta_1 = \eta_2 = ... = \eta_T,$$

whereas the alternative hypothesis of presence of a structural break is:

$$H_1 : \theta_1 = ... = \theta_{k^*} \neq \theta_{k^*+1} = ... = \theta_T \text{ and } \eta_1 = \eta_2 = ... = \eta_T$$

If the null hypothesis is rejected, k^* is the time of the single change-point. If the breakpoint is known, the test statistic is based on a generalized likelihood ratio test.[12] The idea behind this test is to verify if a population can be better explained by separating the total sample in two parts. The following equation corresponds to the likelihood ratio statistic:

$$LR_k = 2\left(L_k(\hat{\theta}_k, \hat{\eta}_k) + L_k^*(\theta_k^*, \hat{\eta}_k) - L_T(\hat{\theta}_T, \hat{\eta}_T)\right)$$

where $L_k(\hat{\theta}_k, \hat{\eta}_k)$, $L_k^*(\theta_k^*, \hat{\eta}_k)$ and $L_T(\hat{\theta}_T, \hat{\eta}_T)$ correspond to the log-likelihood functions of the copula in equation (13) before the break, after the break and for the

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[12] For further details, see Dias and Embrechts (2004) and Csörgő and Horvàth (1997).

full sample. In a more realistic case where the breakpoint date is unknown, a recursive procedure is used and the test statistic becomes:

$$Z_T = \max_{1 \leq k < T} LR_k \tag{16}$$

The null hypothesis will be rejected for large values of this statistic. The critical values are computed according to the approximation for the distribution of $Z_T^{1/2}$ proposed by Csörgő and Horvàth (1997) and also used by Dias and Embrechts (2004). For further details on this approximation, see the references mentioned.

Then, for estimating the time of the breakpoint, the maximum likelihood estimator of this time is given by:

$$\hat{k}_T = \min\{1 \leq k < T : Z_T = LR_k\} \tag{17}$$

This estimator will take a value near the boundaries of the sample if we cannot conclude to the presence of a change-point. In the case where we suppose that several changes in the copula parameters might exist, we adopt a sequential procedure proposed by Vostrikova (1981), also used in Dias and Embrechts (2004). This method consists in a segmentation procedure of our sample at each time we find a significant break. If the null hypothesis is rejected for the full sample, the breakpoint is used as a boundary for constructing two subsamples (one before the change and one after the change), where we apply again our likelihood ratio test to each of them. The segmentation procedure continues until we do not find a significant breakpoint in any of the sets.

In order to evaluate the contagion phenomenon in real estate stock markets, we re-estimate the lower and upper tail dependences from the static SJC copula for each subsample constituted by the structural break test presented above and analyze the changes in the parameter values. At least one parameter must significantly change for there to be a break. For having financial contagion, we must observe an increase of the lower tail dependence after a shock. We also rerun the time-varying copula for each subsample and plot the tail dependences with the structural break(s) for a more visual analysis of the contagion patterns.

V. EMPIRICAL RESULTS

This section is divided in four parts. First, the volatility spillovers are discussed through the examination of the news impact surfaces for both types of analysis (i.e. domestic and international). Second, the results from the static copula analysis of the tail dependences are commented. The third part is devoted to the dynamic aspect of the previous investigations. In this subsection, we also confront the time-varying correlations and tail dependences estimated. Finally, the outcomes of our measure of financial contagion are discussed in the last subsection.

V.I VOLATILITY SPILLOVERS

DOMESTIC ANALYSIS

The parameter estimates of the bivariate asymmetric t-BEKK model for the domestic analysis are reported in Table 3. Several parameters are statistically significant for each country; the results for Australia exhibiting, however, less significance than those for the U.S. and U.K. Those parameters are not utilized for interpreting the volatility transmission dynamics, however, due to the difficulties to trace those dynamics because of the quadratic form of the model. The model captures some leptokurtosis through the degree of freedom parameter (highly significant) of the Student's *t*-distribution and fits well the data based on the Ljung-Box Q-test performed on the squared standardized residuals (no autocorrelation left). To gauge the importance of the asymmetric part added to the model, we also conduct a likelihood ratio test (LRT)[13] on the three series and conclude that this addition increases the explanation power of the model.

[Insert Table 3 about here]

Figure 1 displays the NIS for the U.S. (on the top, for the variance of securitized real estate and stocks; at the bottom, for the covariance and the correlation). The securitized real estate variance is larger when its own lagged innovations are negative, supporting the idea of asymmetry. The variance is even larger when its own negative innovations are combined with positive shocks coming from the stock market, meaning that the securitized real estate market is the most volatile when the equity

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[13] The results of this test are not reported. They can be obtained upon request.

market performs well whereas it declines. The spillover effect from the stock market to the real estate market is quite apparent given that the real estate variance changes for varying levels of news coming from the equity market (for a given level of real estate news). However, this is the case only when the real estate innovations are large. Some asymmetry appears in the spillovers, especially when we have positive shocks stemming from the real estate market. Relatively similar patterns are found for the equity variance dynamics; however, with a more pronounced asymmetry.

[Insert Figure 1 about here]

The conditional covariance reaches its highest level when the shocks from the two markets are of opposite sign, whereas the correlation is particularly strong at each extreme situation except in the case where the news are extremely positive for both markets. The correlation behavior reinforces the idea of asymmetry in the inter-linkages between the two assets studied. In sum, stocks and real estate securities are strongly linked and they mutually influence their volatility.

The NIS related to the U.K. market are reported in Figure 2. In comparison to the U.S. case, quite different conclusions should be drawn. Indeed, the securitized real estate variance is slightly influenced by the news from the common stock market, but only so when the innovations in the real estate market are extremely negative. In contrast, the securitized real estate market has almost no impact on the equity variance. Furthermore, the asymmetric behavior of the variance appears only according to the lagged innovations, the spillover effect remaining stable. The NIS of the covariance and the correlation are quite flat except when both assets produce negative shocks leading to an increase of the covariance and the correlation.

[Insert Figure 2 about here]

Figure 3 shows that the Australian real estate stock variance is not very sensitive to the news arriving from the broader stock market, forming an U-shape. Thus, we can observe a strong symmetry characterizing the variance reaction to its own shocks. On the other hand, the stock variance is positively influenced by positive real estate news when its own innovations are negative and otherwise it exhibits a rather stable variance without noticeable asymmetric behavior. The covariance NIS is bowl-shaped and the correlation is the highest with both positive and negative extreme

shocks (saddle shape) confirming the previous observation of symmetry, namely that the markets are almost equally linked during bearish markets than during bullish markets.

[Insert Figure 3 about here]

In summary, the results for the U.S. suggest tighter linkages across the two assets than is the case in the U.K. and Australia. In general, one would expect a strong asymmetry driving the conditional real estate stock variance because real estate companies generally employ high leverage levels. Indeed, given the underlying assets of those companies (i.e. real estate), lenders are willing to provide loans covering a large fraction of the assets' values. This asymmetry should be particularly strong in the U.S. given that real estate companies are much more leveraged than those in the two other countries (Serrano and Hoesli, 2009). Our results confirm these hypotheses.

INTERNATIONAL ANALYSIS

In this section, we introduce an international dimension in our study by evaluating the relationships between the world securitized real estate market and the domestic securitized real estate market in each of the three countries. At this stage, we take the point of view of a local investor who is unhedged against the exchange rate risk. Table 4 exhibits the results of the specific bivariate GARCH utilized in this paper. We observe now a certain equality in the level of significance in the parameters across the series. Again, the fat tail feature of the data has been captured by the shape parameter of the Student's *t*-distribution and the LRT rejects the null hypothesis of no improvement of the model by adding the asymmetric part to the GARCH model. No autocorrelation is found after the model's estimation.

[Insert Table 4 about here]

The empirical results from the international analysis are not in line with what might have been expected. Indeed, the news coming from the world market have little impact on the domestic markets studied (Figures 4, 5 and 6; top left of the figures). The U.K. and the Australian variances are weakly related to the world market news, whereas the U.S. variance is solely driven by its own news. However, since we are

studying important countries in terms of economic might and real estate security market capitalization, it is not all that surprising to find the U.S., U.K. and Australian markets influencing the variance of a global index (top right of the figures). The asymmetry is present in the spillover effects but less so for Australia, showing that the interactions are tighter when markets decline globally. Each series also exhibits an asymmetric behavior according to its respective own lagged innovations. The covariance and correlation patterns are in line with volatility spillover and asymmetry findings, with higher levels when both series have extreme negative shocks (bottom of the figures referenced).

[Insert Figures 4/5/6 about here]

The U.S. being the world's largest economy, its influence on the world securitized real estate market is quite understandable. One possible explanation for the U.K. and Australian results might be the presence of regional or continental factors (Eichholtz et al., 1998) and the importance of those two economies in their respective region. Such regional factors could stem, for instance, from the fact that those countries have many trade agreements with countries in their area. By their influence on those regions in which other important markets also exist (for instance, France or Germany for Europe and Japan and Singapore for Asia), indirect repercussions may appear on the world index volatility. The hypothesis of regional factors influencing the securitized real estate markets might also be supported by the characteristics of such an asset. Indeed, due to the fact that real estate stocks behave to some extent as small capitalization stocks (Stevenson, 2002), they should be more correlated to local, national, and regional economic activities (Bardhan, Edelstein and Tsang, 2008).

Those findings concerning continental factors may also suggest stronger links of securitized real estate markets with direct real estate markets due to the importance of the 'home' bias. Indeed, it is well known that people invest more in direct real estate in the region of their home country because some knowledge of the local economy is crucial, leading to national or regional factors influencing the real estate market. Thus, investors purchasing international real estate securities may behave in a similar fashion because they consider that this asset has similar risks or characteristics as its underlying asset.

The increasing tendency of introducing REIT-type structures across the world also contributes to reinforce the international inter-linkages. Indeed, the tax-transparency inherent to a REIT system leads to increased transparency of the companies as a whole allowing potential and current investors to obtain more complete information about the financial prospects for such companies. Thus, the possibilities to invest abroad are more practicable and the information flows easier.

ROBUSTNESS CHECKS

This part is devoted to the analysis of the sensitivity of the relationships found in the previous section to the exchange rate dynamics. So, the volatility transmissions are studied from the perspective of an investor who is hedged against currency risk. This goal is reached by expressing the global securitized real estate index in local currency (each domestic market included in the global index is denominated in its own currency). Although some differences emerge, the U.S. and U.K. interactions with the world market are not dissimilar. The changes for Australia are more pronounced in the volatility spillover patterns as well as in the asymmetry. The main change is that the news arriving from Australia do not have any impact on the world market anymore. Thus, the inter-linkages found in the previous section concerning that country appear to be driven largely by exchange rate factors.

V.II CONSTANT TAIL DEPENDENCES

The purpose of this section is to evaluate the inter-linkages between markets during extreme conditions. To do so, both lower and upper tail dependence coefficients are estimated from the SJC copula (Table 5). Panel A contains the results of the domestic analysis. Overall, the levels of the tail dependences are quite important in the three markets, with parameters ranging from 0.25 to 0.50. According to the standard errors of these estimates, we reject in each case significantly the tail independence hypothesis. Another striking feature are the generally higher coefficients observed in the lower tail dependences in comparison with those in the upper tail dependences. A Wald test is performed to analyze the tail symmetry hypothesis. We find that an asymmetric feature characterizes the tail dependence dynamics in each market. Thus, the equity market is much more connected to the real estate stock market when both markets are crashing than when they are booming, consistent with financial theory. These points provide further evidence on the opportunities to diversify a mixed-asset portfolio as we obtain information on the

joint behavior of these assets in the tail distribution as well as on the asymmetry characterizing their dependence structure, what a simple linear correlation measure cannot achieve.

[Insert Table 5 about here]

Panel B shows the tail dependence results at the international level (with an unhedged strategy). All coefficients are statistically significant. The strongest lower tail dependence is registered for the U.K. (0.36), then the U.S. (0.26), with Australia exhibiting the lowest value (0.19). The upper tail dependences are usually weaker than the lower ones, except in Australia. The Wald test results validate the tail asymmetry for the U.S. and the U.K. and conclude to tail symmetry in Australia.

Consistent with our volatility spillover findings, our robustness checks[14] point out the importance of the exchange rate factors only on the results between Australia and the world market. The lower tail dependence increases notably, but without affecting the Wald test results (the tail symmetry remains). The results for the two other countries remain unchanged.

V.III   TIME-VARYING TAIL DEPENDENCES & CORRELATIONS

This section introduces a dynamic feature in the dependence measures. For comparison purposes, we also calculate conditional correlations from the asymmetric t-BEKK model used to gauge the presence of volatility spillovers. As Longin and Solnik (1995) show that the correlations are not constant through time, we can assume that a different picture (in comparison to a static analysis) should also emerge from the dynamic tail dependences. We will be able to evaluate the differences in the dynamics over our sample period between the conditional correlations and tail dependences. Thus, this part should contribute to the debate on the limits of using the correlation measure as relevant information for portfolio decision-making by disentangling the patterns underlying its evolution.

The conditional tail dependences and correlations plotted are smoothed tail dependences and correlations calculated using a rolling-window process with a 50-observation window. Such smoothing is needed to extract clear trends. The lower

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[14] The results are not reported in this paper. They can be obtained upon request.

and upper tail dependences are plotted in the same graph for each pair, whereas the graphs for the correlations contain, for each specific analysis, the correlations for the three markets under investigation.

[Insert Figures 7/8/9 about here]

The time-varying lower and upper tail dependences for the local analysis are plotted in Figures 7, 8 and 9. The patterns in the three countries are quite similar with some constancy in the linkages between equities and real estate securities from the beginning of the sample period until 2005-2006 (coefficients of about 0.40-0.50 for the lower tail dependences and of 0.30 for the upper tail dependences). Naturally, some spikes are registered occasionally during this period but the coefficients return to a stable level not long thereafter. The main feature to notice is the upward trend from 2005-2006 observed in Australia, also present in the U.S. and the U.K. but less importantly so and only for the upper tail dependence. Therefore, the Australian securitized real estate market has an increasing tendency to behave like the broader stock market during extreme conditions since 2005. Otherwise, clear asymmetry characterizes the conditional tail dependences, a feature that cannot be captured by the correlations.

The conditional correlations in the three countries (Figure 10) exhibit quite similar tendencies for the first fifteen years compared to the evolution patterns of the tail dependences, namely a constant trend with coefficients around 0.50-0.60. On the other hand, the period 2006-2010 shows different features in terms of dynamic behavior. Indeed, we obtain now a strong positive trend in the three countries.

[Insert Figure 10 about here]

Concerning the international analysis (for an investor without currency risk hedging), the results are less consistent across countries (Figures 11, 12 and 13). The asymmetry is particularly marked in the U.K. and to a lesser extent in the U.S., whereas results suggest no clear asymmetry in Australia (similar conclusions were reached with the constant SJC copula). We find coefficients of about 0.25 and 0.10 in the U.S. and 0.35 and 0.10 in the U.K. on average, respectively for the lower and upper tail dependences. As for Australia, coefficients of about 0.20 on average (for

both tail dependences) are observed. Finally, except some peaks, constant tendencies over the 1990-2010 period are observed in the three countries.

[Insert Figures 11/12/13 about here]

As in the case with the local analyses, the dynamics of the conditional correlations (Figure 14) diverge from those of the conditional tail dependences in the three countries. Again, we observe an increase in the correlations from 2007. Globally, these findings are not driven by exchange rate factors underlying the joint behavior of the series as we find robust results[15] if we carry out the study with a currency risk hedging strategy.

[Insert Figure 14 about here]

In general, a well diversified portfolio in usual times does not necessarily imply that it will be satisfactory diversified in stressful times; consequently consideration of the extreme joint behavior of financial series is crucial. This is particularly true due to the fact that the biggest losses occur during extreme situations. Therefore, the financial implications of our findings, supportive of the idea that different dynamics underlie the evolution patterns of the correlations and the tail dependences, are important.

V.IV FINANCIAL CONTAGION

This section is devoted to the study of financial contagion in securitized real estate markets. We combine two methodologies for testing for contagion, namely the copula and the structural break test. More specifically, we investigate the presence of structural breaks in the tail dependences without exogenously defining the time of occurrence of a shock. Thus, we adopt the definition of Forbes and Rigobon (2002) and the intuition of Bae, Karolyi and Stulz (2003) who assess "the coincidence of extreme return shocks across countries" when examining the evidence of contagion.

The pairs of series utilized are not the same as those used in the previous sections. Indeed, as our main aim is to test for the presence of financial contagion after the recent financial crisis, we focus only on the pairs including the U.S. market. This latter country has been identified as being the source of the global financial crisis as a

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[15] The results are not reported in this paper. They can be obtained upon request.

consequence of the prior subprime crisis. Hence, we carry out our study of financial contagion for three pairs: the U.S. and U.K. securitized real estate markets; the U.S. and Australian securitized real estate markets; and finally the U.S. equity and securitized real estate markets.[16] Table 6 reports the results of the structural break test[17] of Dias and Embrechts (2004) as well as the dates of the structural breaks found.

[Insert Table 6 about here]

From the three pairs under analysis, only the pair U.S.-Australia does not experience any structural break over our sample period meaning that their inter-linkages expressed by their tail dependences have not significantly changed these past twenty years. Consequently, we do not find any evidence of the crisis spreading from the U.S. to Australia during the recent financial turmoil. Indeed, with a test statistic of 3.06, there is not sufficient evidence to reject the null hypothesis of no change in the copula parameter(s). The estimates of the constant SJC copula (Table 7) exhibit low levels of tail dependences (0.11 and 0.08 for the lower and upper tail dependences, respectively), which suggests very weak links between these two markets. Moreover, the Wald test for tail symmetry cannot be rejected.

A straightforward explanation is the presence of regional factors driving the real estate returns as already found in the volatility spillover analysis and also shown by Eichholtz et al. (1998), complicating the propagation of shocks beyond the limits of a region. Also, the weak economic and political relationships shared by the U.S. and Australia, for instance the lack of trade links, support the finding of no change in the fundamental relations between the two markets. International agreements constitute an important channel of shock transmission by means of increasing the information flows between partners as argued in Longstaff (2010)[18] and shown empirically by Forbes (2002).

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[16] The indices are expressed in local currency in order to avoid any impact of exchange rate factors on the analysis of financial contagion.

[17] As we filtered our returns with an AR(1)-GJR-t-GARCH(1,1) model, we can assume that we have independent bivariate vectors with no structural break in the margins; therefore the conditions for applying the test of Dias and Embrechts (2004) are satisfied.

[18] Longstaff (2010) reviews two other mechanisms of shock transmission: contagion trough the liquidity channel and contagion through the time-varying risk premiums. These mechanisms are not discussed in this paper as they do not constitute the purpose of our study.

[Insert Table 7 about here]

The structural break test suggests a significant change in the copula parameter(s) modeling the extreme joint behavior of the U.S. and U.K. real estate stock markets. The test statistic takes the value of 4.30 and the null hypothesis is rejected with a p-value of 0.01 (Table 6). The estimated time of the change occurred on January 26, 2007. The segmentation procedure used for testing multiple changes does not show other significant breaks in the two subsamples resulting from the first step. From Table 7, we observe a sharp increase of the lower and upper tail dependences reaching 0.55 and 0.31 after the break (about four times the values of the first subsample) and a switching from tail asymmetry to tail symmetry. Hence, we can conclude that the fundamental relations between the U.S. and U.K. markets changed and became tighter since the beginning of 2007. This date corresponds to the peak of the subprime crisis leading to the conclusion that this shock spread from the U.S. to the U.K.; this is consistent with the definition of financial contagion.

We notice that the contagion appeared before the recent financial crisis in the U.S., meaning that the catalyst of the financial contagion in the securitized real estate market was not the recent financial crisis but rather the subprime crisis. As we do not find another structural break later, we can assume that the new relationship patterns have been driven essentially by the subprime crisis. The past has shown in several instances the tight economic and political relations between the U.S. and the U.K., being favorable conditions for such a shock transmission. According to the results of Kallberg, Liu and Pasquariello (2002), who find that the country's exposure to trade and the firm leverage are noticeable factors for explaining the structural breaks, we can have the same rationale for explaining the contagion phenomenon existing between the U.S. and the U.K. markets.

Finally, we find two significant structural breaks in the tail dependence(s) between the equity and real estate stock markets in the U.S. (Table 6). The corresponding dates are January 05, 1996 and December 03, 2004 and their respective test statistics take the values of 3.88 (p-value of 0.03) and 5.55 (p-value of 0). The remaining of the subsamples stemming from the segmentation procedure do not show any other significant break. The estimates of the constant SJC copula parameters for the three subsamples illustrate the strong relationships between these two assets. The weakest tail dependences are registered in the intermediate period (1996-2005), while the

highest values occur during the period 2005-2010. The most important increase occurred to the upper tail dependence between the second and the third subsample.[19] As regards the Wald test, it rejects the null hypothesis of tail symmetry only for the period 1990-1996. To summarize, the extreme links dropped in 1996 and rose again in 2005 reaching coefficients of about 0.62 and 0.55 (lower and upper tail dependences, respectively) and behave in an increasingly symmetric fashion.

The structural breaks found previously are not the manifestation of a financial contagion phenomenon as no particular crisis corresponds to the time of the changes. Nevertheless, other important economic phenomena may explain these changes in the fundamental relationships. The 1990s coincide with a growth in U.S. securitized real estate markets. These facts lead to a much more complete informational content weakening the relations between stocks and REITs (Khoo, Hartzell and Hoesli, 1993). The second change might be due to the real estate bubble in the U.S. preceding the subprime crisis. This is confirmed by the fact that the largest changes are reported in the upper tail dependence for this structural break (the prices were especially high during the period preceding the subprime crisis).

For a more visual support we also decided to estimate the time-varying tail dependences resulting from Equations (14) and (15)[20] with the various structural breaks found in the static case. These measures are plotted in Figures 15, 16 and 17; the results are robust with respect to those reported with the constant SJC copula.

[Insert Figure 15/16/17 about here]

In summary, from the three pairs tested, we observe a contagion phenomenon only between the U.S. and the U.K. real estate security markets occurring in 2007, the other pairs of markets showing either no structural break (the U.S. with Australia) or the presence of breaks which are not due to a crisis (the U.S. real estate stock market with the broader stock market). The implications are basically twofold. First, the relationships between assets or between markets are not the same whether or not we consider the possibility of regime switching and this may result in important consequences in terms of over or under-estimation of risks. Second, the economy of

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[19] The significant change could have occurred only on the upper tail dependence as we test for a change in one parameter only or in both parameters.

[20] The results of these estimations are not reported. They can be obtained upon request.

a country may be seriously affected by significant changes occurring in a larger economy as shown by the spreading of the financial crisis from the U.S. to the rest of the world, causing a strong recession in numerous countries and affecting other sectors as well.

VI. CONCLUDING REMARKS

In this article, we investigate the relationships between local equity and securitized real estate markets, but also those existing between the world real estate security market and three local markets (i.e., those of the U.S., the U.K. and Australia). Three aspects of those relationships are considered in order to obtain a global view of the underlying features. First, the volatility spillover patterns are analyzed using an asymmetric t-BEKK model. Second, using an approach embedded in copula theory, we estimate both constant and time-varying tail dependences. More specifically, we have chosen the symmetrized Joe-Clayton copula proposed by Patton (2006) because of its flexibility. Third, we test for financial contagion in the sense of Forbes and Rigobon (2002) and Bae, Karolyi and Stulz (2003). For doing so, we look at the presence of structural breaks in the previous copula parameters (i.e., in tail dependences) by employing the test of Dias and Embrechts (2004).

Our article yields the following main results:

1. The strongest volatility spillovers between the stock and the securitized real estate markets are found in the U.S.
2. The three national markets influence more the volatility of global market than the reverse.
3. Rather important tail dependence coefficients are observed (in both domestic and international analyses).
4. A quite constant trend is found in the time-varying tail dependences over the 1990-2010 period (except for Australia in the domestic analysis), contrasting with the conditional correlations which show a clear upward trend since 2005.
5. Generally, currency movements do not contribute to our findings.
6. Evidence of financial contagion is only found between the U.S. and the U.K. markets and follows the subprime crisis.

Our analysis sheds light on the complexity of the dynamics underlying the securitized real estate markets and should prove useful in devising international real estate security portfolio strategies. Given that direct real estate and real estate securities exhibit rather strong linkages in the longer term and knowing that real estate and housing markets have a noticeable impact on the economy of a country (the recent subprime crisis is a clear illustration of this), the results of this paper should also be useful to policy makers.

Three avenues for future research should be fruitful. An extension of this paper would be to test for financial contagion by means of a structural break test which would take into account the time-varying feature of the tail dependences. Further, a more detailed analysis of the shock transmission mechanisms underlying the financial contagion would expand this line of research. Also, consideration should be given to the implications of our results for return predictability and market efficiency.

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TABLES

Table 1. Summary Statistics - Real Estate Stocks

Statistics

	U.S.		U.K.		Australia	
Mean	0.225		0.057		0.165	
Std Deviation	3.024		2.960		2.514	
Skewness	-0.472		-0.899		-2.076	
Kurtosis	16.467		9.612		22.420	
Jarque-Bera	8,088.024	**	2,083.421	**	17,500.653	**
ADF unit-root	-13.492	**	-12.751	**	-14.475	**
Q(12)	26.017	*	26.509	**	147.132	**
Q^2(12)	1,355.217	**	865.809	**	575.559	**
ARCH(1) LM test	359.909	**	113.969	**	7.940	**

This table presents descriptive statistics at the weekly frequency for real estate stocks for the period December 28, 1989 to May 28, 2010. The mean and standard deviation are expressed in percentage.

Table 2. Correlations - Returns

Panel A: Real Estate Stocks - Stocks

	U.S.	U.K.	Australia
Coefficients	0.612	0.619	0.626

Panel B: Real Estate Stocks - Global Real Estate Stocks

	U.S.	U.K.	Australia
Coefficients	0.459	0.510	0.398

In this table, the correlation coefficients are shown between real estate stocks and stocks (Panel A) and real estate stocks and global real estate stocks (Panel B).

Table 3. Asymmetric BEKK results - Local Analysis

Parameters	Coefficients (robust t-stats)					
	U.S.		U.K.		Australia	
a_{11}	-0.290	(-4.17)	0.171	(2.58)	0.245	(5.83)
a_{12}	-0.179	(-5.93)	0.033	(0.30)	0.029	(0.26)
a_{21}	0.098	(2.89)	-0.030	(-0.07)	0.012	(0.58)
a_{22}	0.219	(6.69)	-0.079	(-1.17)	0.036	(0.13)
b_{11}	0.950	(48.29)	0.967	(49.83)	0.965	(16.34)
b_{12}	-0.002	(-0.23)	0.013	(0.75)	0.039	(0.63)
b_{21}	-0.029	(-2.14)	-0.031	(-0.80)	-0.011	(-0.10)
b_{22}	0.938	(50.53)	0.932	(22.84)	0.924	(10.47)
n_{11}	0.279	(5.08)	0.237	(1.45)	-0.038	(-0.11)
n_{12}	0.045	(1.29)	-0.002	(-0.02)	-0.240	(-1.91)
n_{21}	0.056	(0.95)	0.131	(1.99)	0.053	(0.22)
n_{22}	0.313	(3.79)	0.394	(3.56)	0.440	(1.96)
DoF	7.365	(6.46)	9.141	(4.13)	9.058	(5.51)
Log-likelihood	5,516.41		5,351.05		5,793.91	
Diagnostic tests						
$Q_1^2(6)$		1.13		8.420		6.935
$Q_2^2(6)$		3.76		2.371		2.970

In this table, the first column shows the coefficient estimates from the BEKK model for the national analysis and the robust t-statistics are reported in parentheses.

Table 4. Asymmetric BEKK results - International Analysis

Parameters	Coefficients (robust t-stats)					
	U.S.		U.K.		Australia	
a_{11}	0.212	(2.19)	-0.058	(-0.97)	0.152	(1.70)
a_{12}	-0.192	(-1.54)	0.071	(1.38)	-0.084	(-0.87)
a_{21}	0.020	(0.19)	0.049	(0.82)	0.060	(0.65)
a_{22}	0.130	(0.80)	0.164	(2.96)	0.214	(2.28)
b_{11}	0.960	(28.28)	0.990	(49.74)	0.957	(52.90)
b_{12}	0.085	(1.71)	0.048	(2.69)	-0.002	(-0.06)
b_{21}	-0.049	(-0.57)	-0.082	(-1.55)	0.005	(0.17)
b_{22}	0.705	(4.47)	0.892	(27.78)	0.947	(26.55)
n_{11}	0.290	(3.53)	-0.271	(-5.90)	0.237	(2.81)
n_{12}	0.365	(2.99)	-0.028	(-0.50)	0.166	(1.13)
n_{21}	0.050	(0.75)	-0.152	(-1.71)	-0.073	(-0.61)
n_{22}	0.299	(3.78)	-0.268	(-4.35)	0.115	(0.38)
DoF	7.399	(6.89)	10.247	(5.41)	7.240	(6.59)
Log-likelihood	5,142.62		5,190.02		5,380.60	
Diagnostic tests						
$Q_1^2(6)$		2.101		6.485		4.403
$Q_2^2(6)$		4.748		4.363		2.555

In this table, the first column shows the coefficient estimates from the BEKK model for the international analysis and the robust t-statistics are reported in parentheses.

Table 5. Tail Dependences - Constant SJC Copula

	U.S.		U.K.		Australia	
Panel A: Real Estate Stocks - Stocks						
Lower	0.471	(0.002)	0.476	(0.002)	0.470	(0.001)
Upper	0.270	(0.001)	0.274	(0.001)	0.345	(0.000)
Wald test	Asymmetric		Asymmetric		Asymmetric	
Panel B: Real Estate Stocks - Global Real Estate Stocks (Unhedged)						
Lower	0.255	(0.002)	0.364	(0.003)	0.188	(0.002)
Upper	0.072	(0.001)	0.102	(0.001)	0.208	(0.002)
Wald test	Asymmetric		Asymmetric		Symmetric	

This table reports the estimated tail dependence coefficients (both lower and upper tail dependences) from the constant Symmetrized Joe-Clayton copula for the period 1990-2010. The standard errors are reported in parentheses. Panel A shows the results for the pair: securitized real estate and stocks and panel B for the pair: local securitized real estate and global securitized real estate. The Wald test results for tail symmetry are also reported.

Table 6. Tests for Structural Breaks in Tail Dependences

	Test Statistic	Sample Size	P-Value	$H_0(0.95)$	Time of change
Panel A: U.S. & U.K. Real Estate Stocks					
I	4.300	1064	0.007	Rejected	26.01.2007
II	3.365	889	0.133	Not Rejected	21.09.1990
	3.500	175	0.063	Not Rejected	13.04.2007
Panel B: U.S. & Australian Real Estate Stocks					
I	3.056	1064	0.297	Not Rejected	-
Panel C: U.S. Real Estate Stocks & Stocks					
I	5.551	1064	0.000	Rejected	03.12.2004
II	3.888	778	0.027	Rejected	05.01.1996
	3.222	286	0.152	Not Rejected	08.05.2009
III	2.964	314	0.282	Not Rejected	20.04.1990
	2.777	464	0.451	Not Rejected	23.01.1998

This table reports the test statistics, the p-values and the time of change from the structural break test of Dias and Embrechts (2004). Panel A shows the results for the pair U.S. and U.K. real estate stock markets; Panel B shows the results for the pair U.S. and Australian real estate stock markets; and panel C shows the results for the pair U.S. stock and real estate stock markets.

Table 7. Tail Dependences with Structural Breaks

	Lower		Upper		Wald test
Panel A: U.S. & U.K. Real Estate Stocks					
1990-2007	0.190	(0.000)	0.007	(0.000)	Asymmetric
2007-2010	0.550	(0.015)	0.313	(0.003)	Symmetric
Panel B: U.S. & Australian Real Estate Stocks					
1990-2010	0.112	(0.002)	0.084	(0.002)	Symmetric
Panel C: U.S. Real Estate Stocks & Stocks					
1990-1996	0.495	(0.002)	0.327	(0.001)	Asymmetric
1996-2005	0.382	(0.005)	0.157	(0.004)	Symmetric
2005-2010	0.617	(0.003)	0.547	(0.002)	Symmetric

This table reports the estimated tail dependence coefficients (both lower and upper tail dependences) from the constant Symmetrized Joe-Clayton copula for the subsamples resulting from the structural break test of Dias and Embrechts (2004); see Table 6. The standard errors are reported in parentheses. Panel A shows the results for the pair U.S. and U.K. real estate stock markets; Panel B shows the results for the pair U.S. and Australian real estate stock markets; and panel C shows the results for the pair U.S. stock and real estate stock markets. The Wald test results for tail symmetry are also reported.

FIGURES
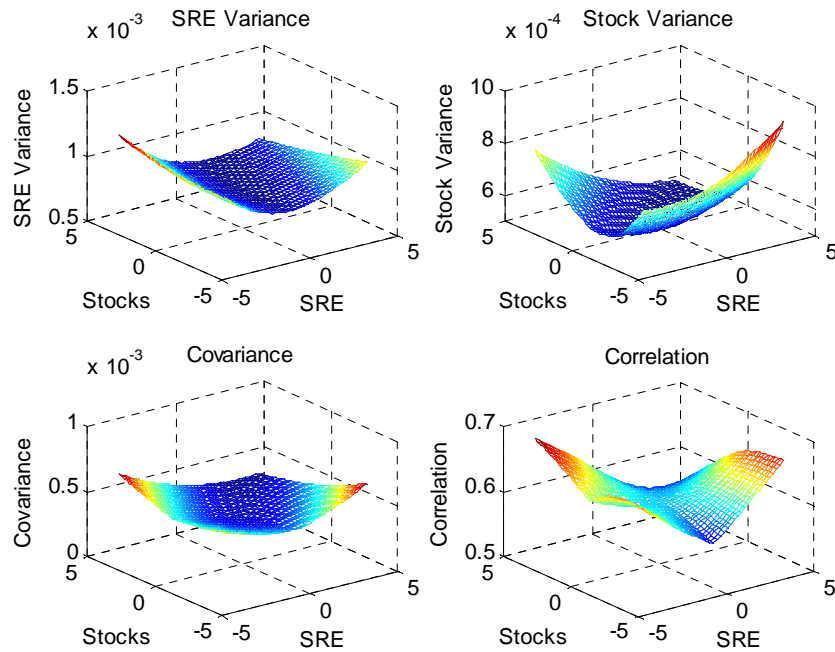
Figure 1. News Impact Curves for the U.S. – Local Analysis
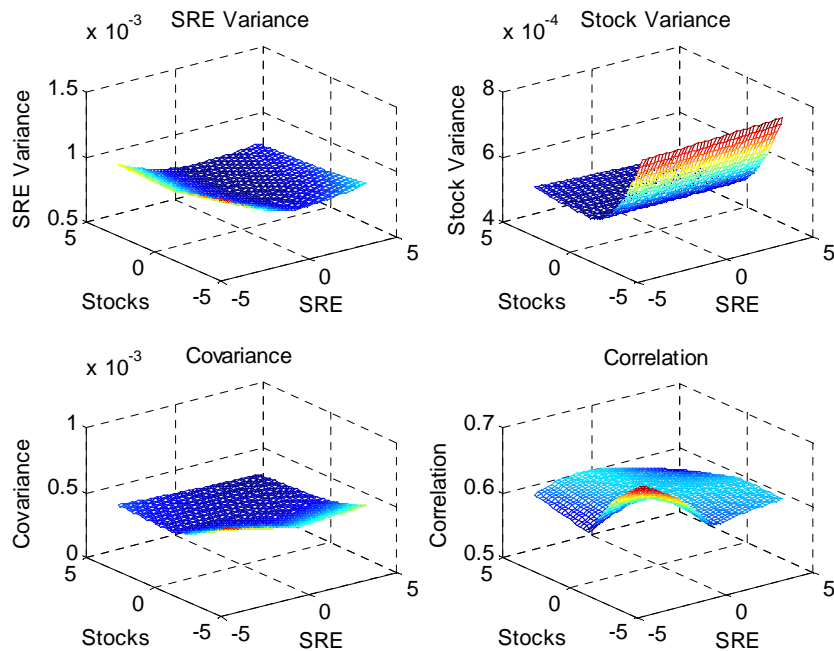
Figure 2. News Impact Curves for the U.K. – Local Analysis
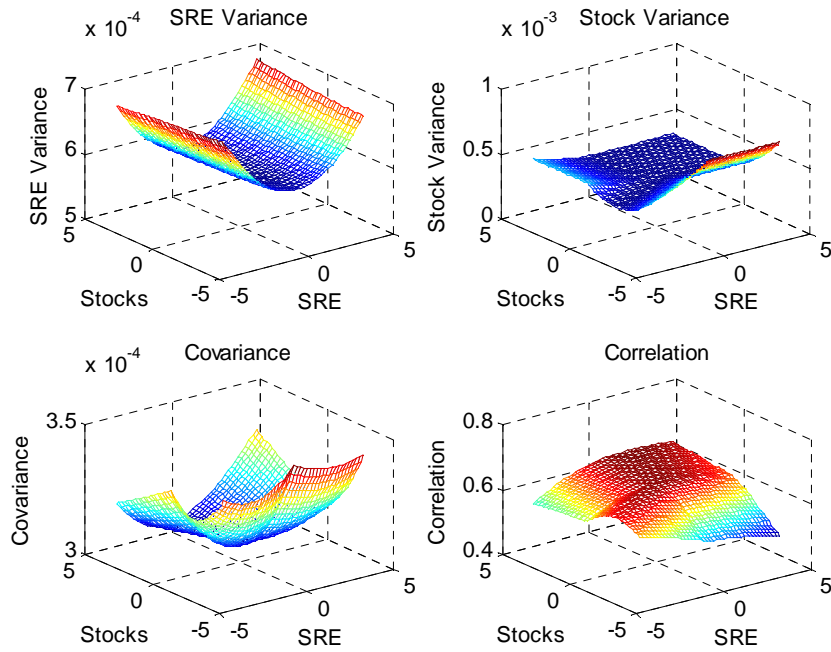
Figure 3. News Impact Curves for Australia – Local Analysis
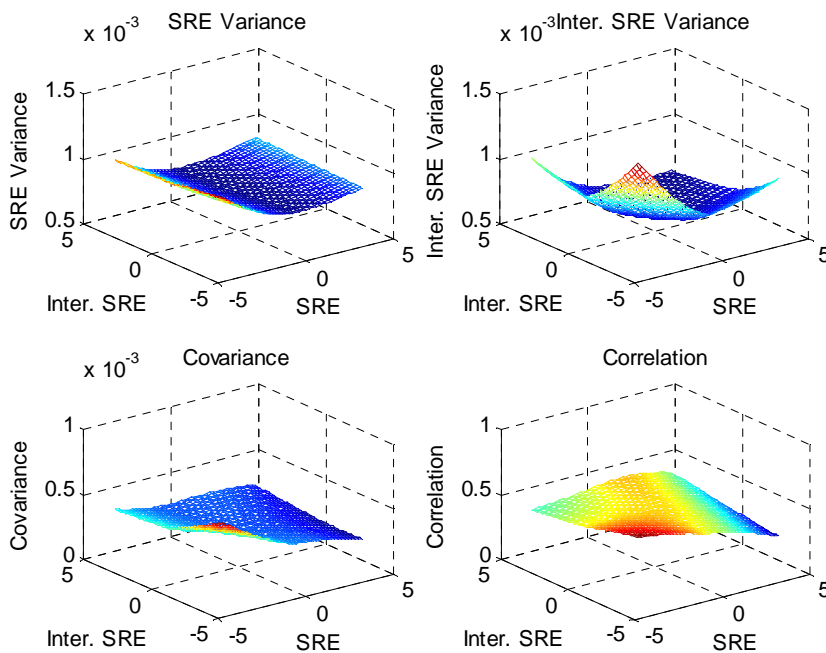
Figure 4. News Impact Curves for the U.S. – International Analysis
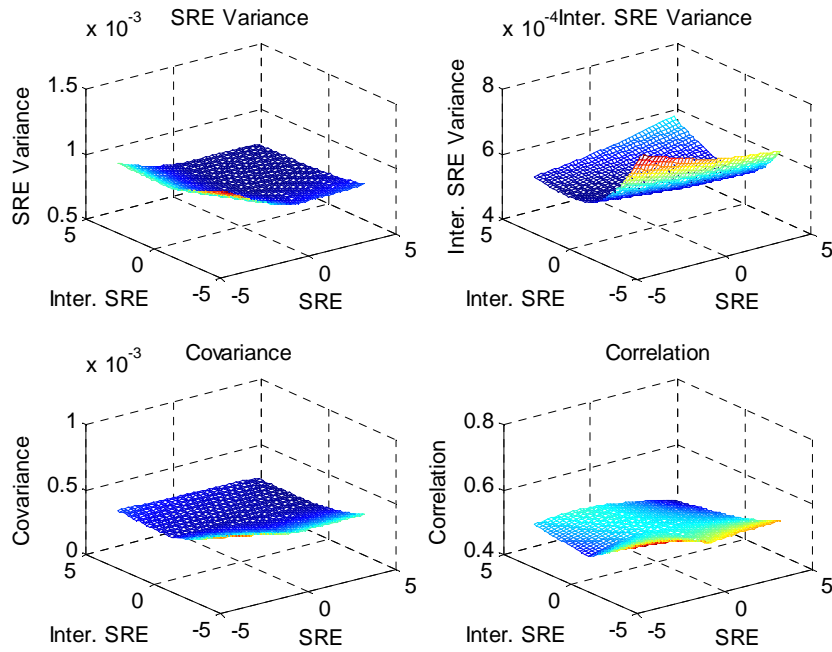
Figure 5. News Impact Curves for the U.K. – International Analysis
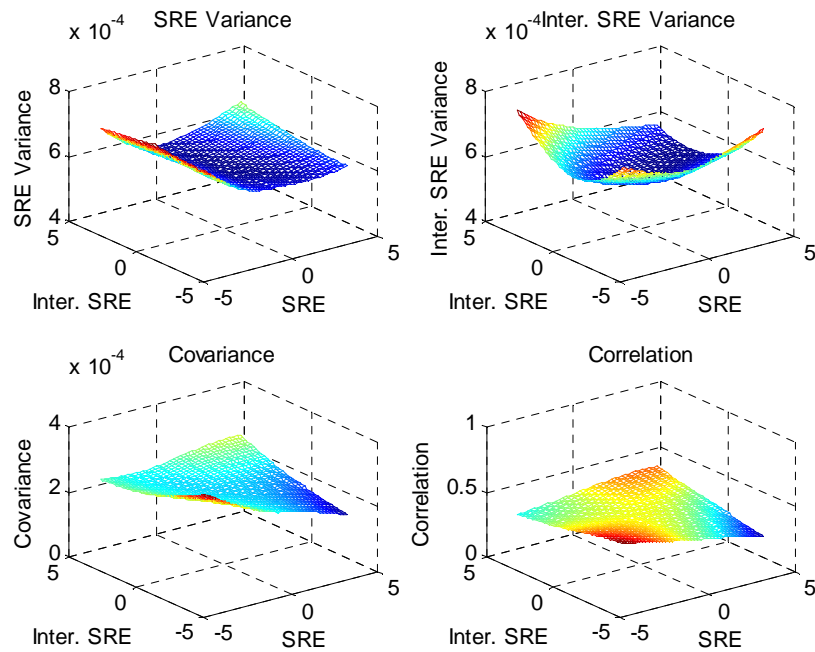
Figure 6. News Impact Curves for Australia – International Analysis
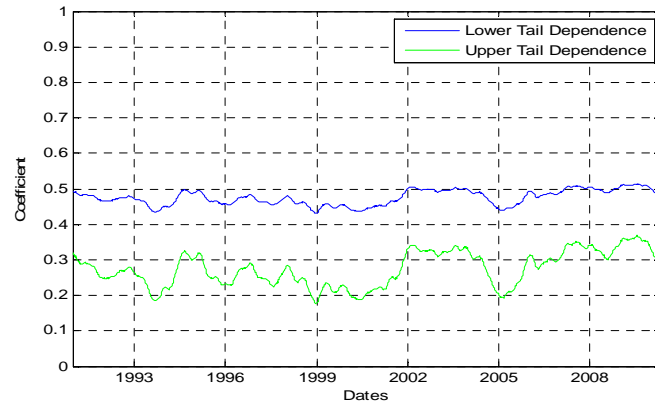
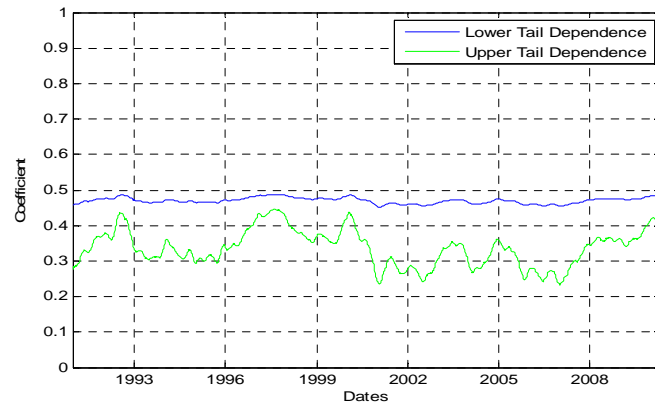Figure 7. Time-Varying Tail Dependences/Rolling-window for the U.S. – Local Analysis

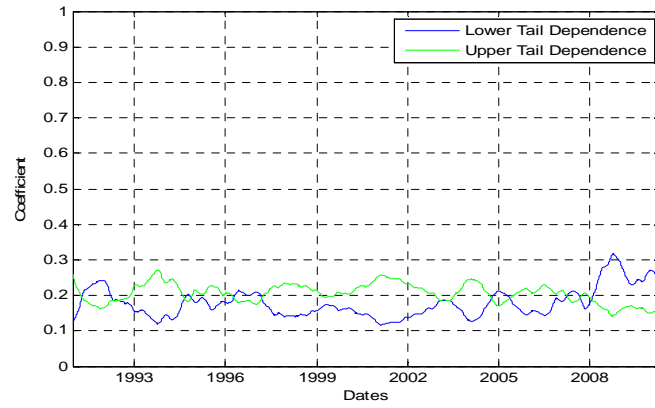Figure 8. Time-Varying Tail Dependences/Rolling-window for the U.K. – Local Analysis
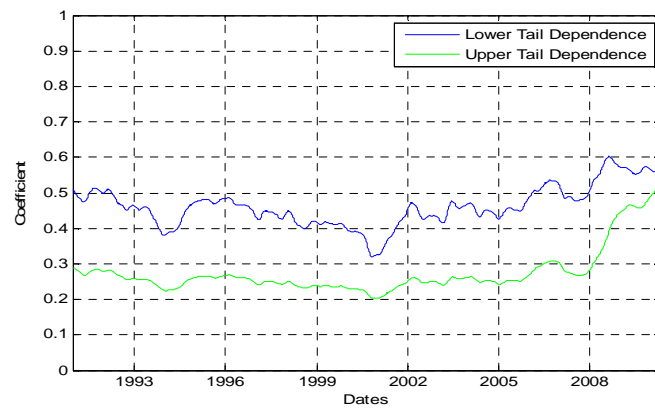
Figure 9. Time-Varying Tail Dependences/Rolling-window for Australia. – Local Analysis
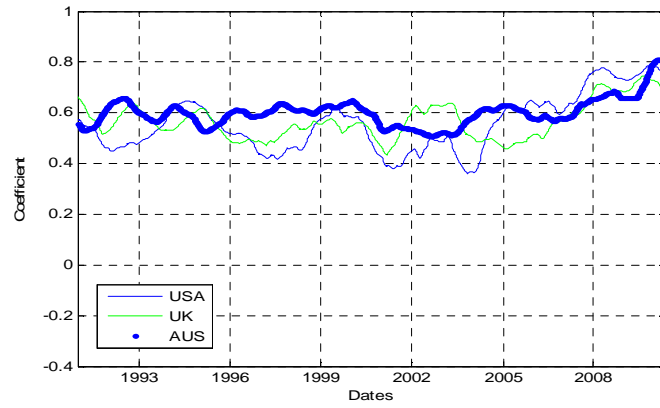
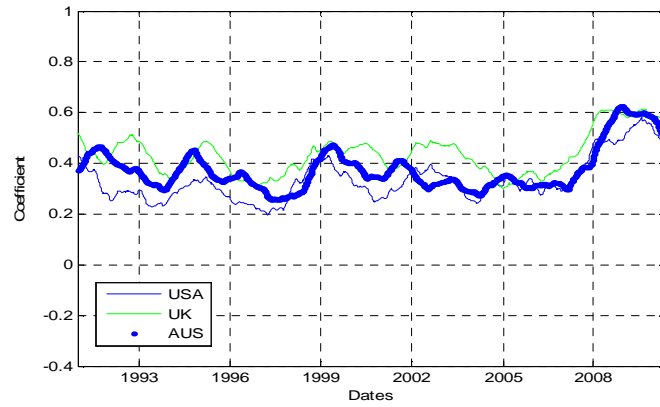Figure 10. Time-Varying Correlations/Rolling-window – Local Analysis
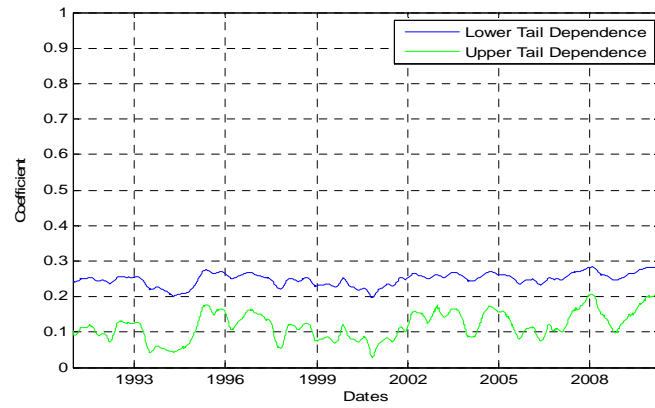
Figure 11. Time-Varying Tail Dependences/Rolling-window for the U.S. – International Analysis
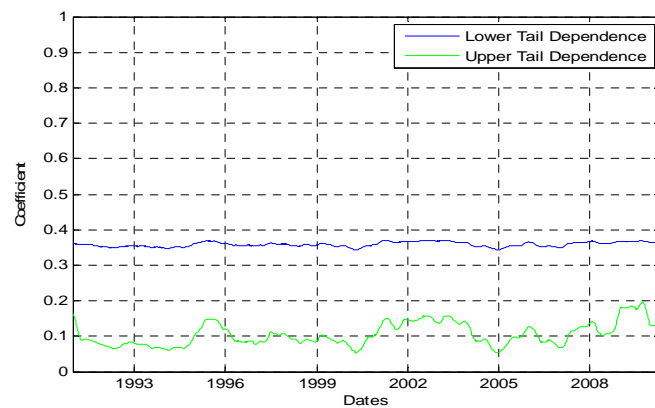
Figure 12. Time-Varying Tail Dependences/Rolling-window for the U.K. – International Analysis

Figure 13. Time-Varying Tail Dependences/Rolling-window for Australia. – International Analysis

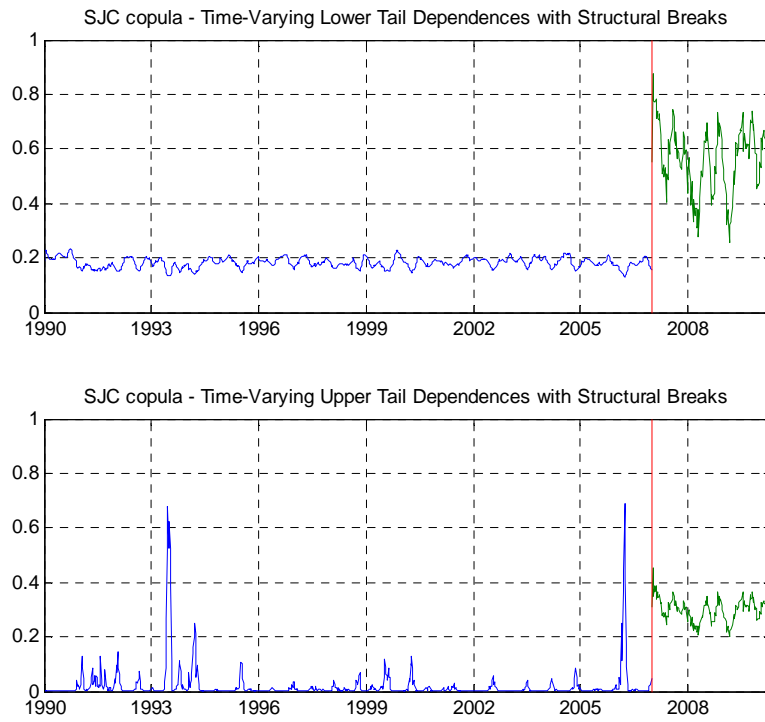Figure 14. Time-Varying Correlations/Rolling-window – International Analysis

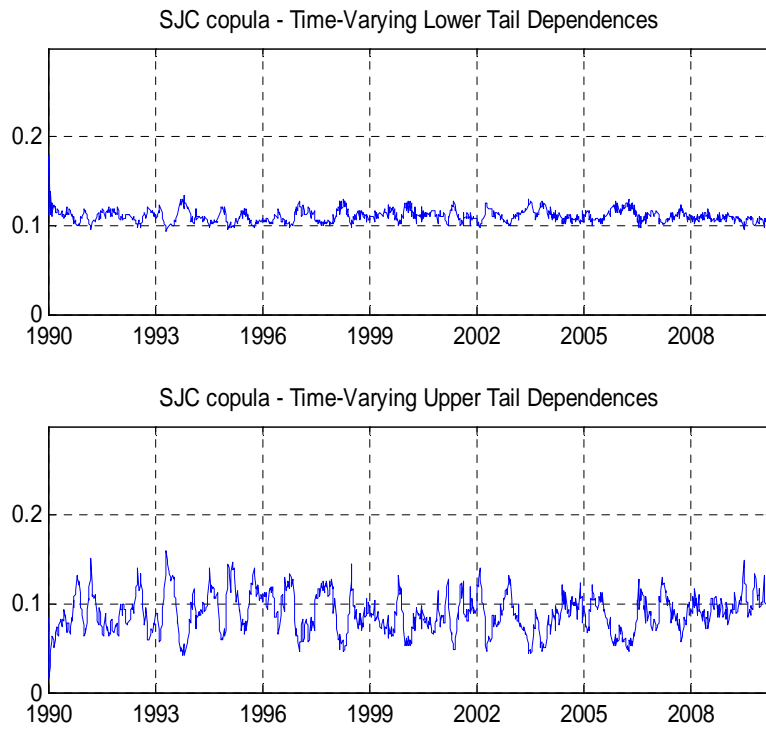Figure 15. Time-Varying Tail Dependences with Structural Breaks – U.S. & U.K.

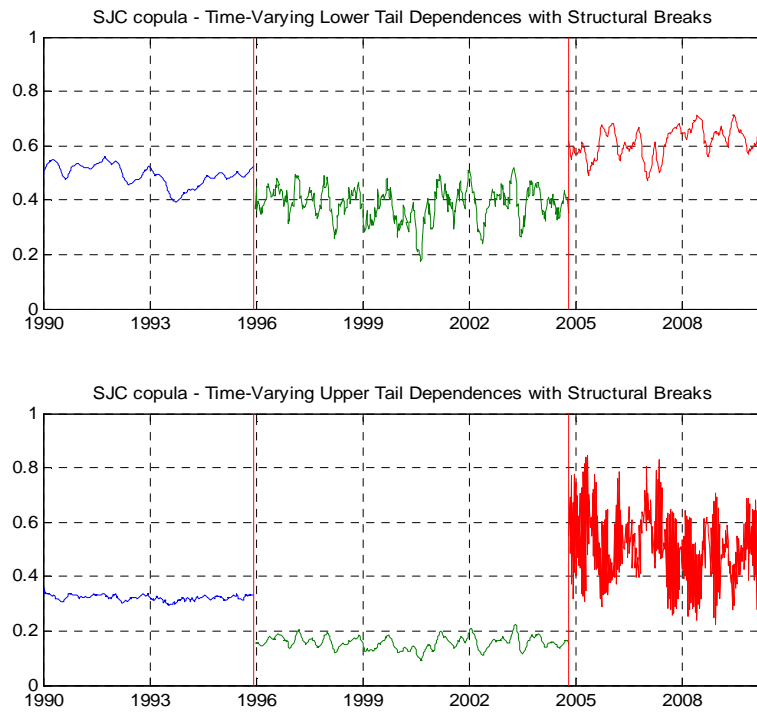Figure 16. Time-Varying Tail Dependences with Structural Breaks – U.S. & Australia

Figure 17. Time-Varying Tail Dependences with Structural Breaks – Stocks & Real Estate Stocks (U.S)