http://economix.fr

Document de Travail

Working Paper
2013-02

A new approach of contagion based on smooth transition conditional correlation GARCH models: An empirical application to the Greek crisis

Henri Audigé

UMR 7235

Université de Paris Ouest Nanterre La Défense
(bâtiment G)
200, Avenue de la République
92001 NANTERRE CEDEX

Tél et Fax : 33.(0)1.40.97.59.07
Email : nasam.zaroualete@u-paris10.fr

A new approach of contagion based on smooth transition conditional correlation GARCH models: An empirical application to the Greek crisis

Henri AUDIGE*

Abstract

The objective of this paper is to gauge how and to which extent the surge in Greek sovereign bond rates in 2010 and 2011 has spilled over the rest of the Euro-area. To this end, we rely on a new class of contagion tests based on Smooth Transition Conditional Correlation GARCH models (STCC-GARCH). Our results highlight the existence of contagion and "wake-up call" effects from Greece to Ireland and Portugal in 2010, and a decoupling in the correlations between Greece and other peripheral countries in 2011. Regarding the core countries, our findings suggest flight-to-quality effects from Greece to Germany and the Netherlands.

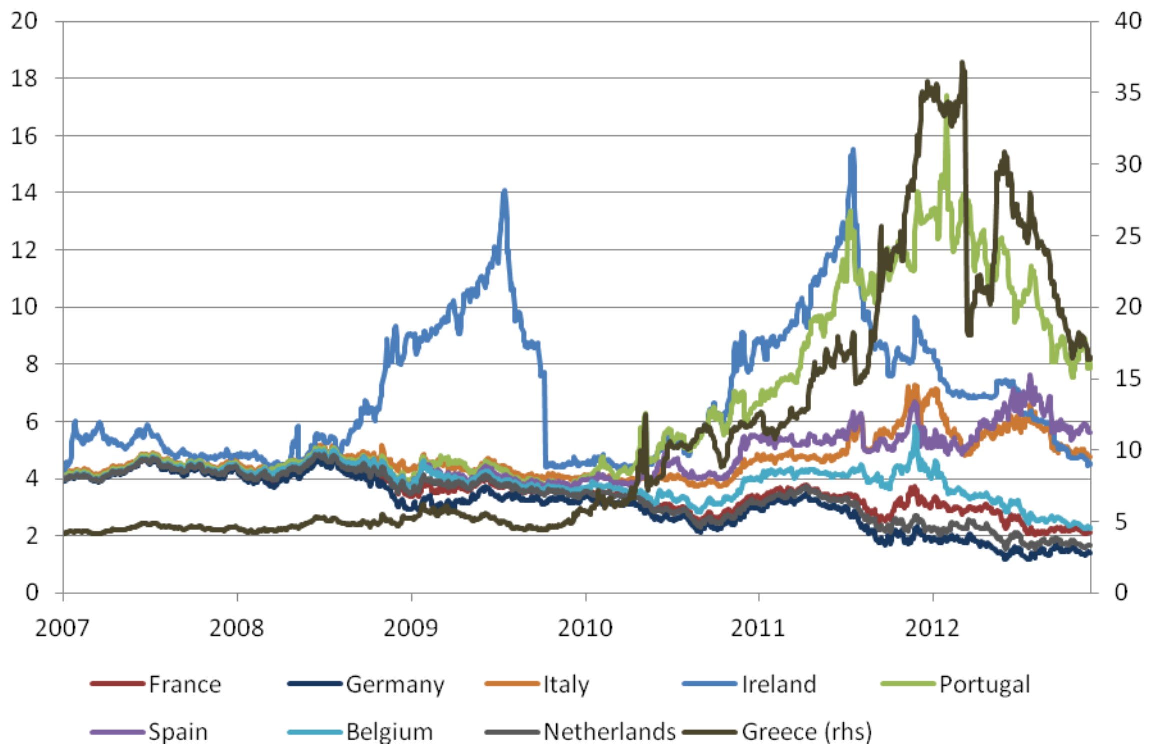
JEL Classification: C32, C58, G01, G12
Keywords: Bond market, contagion, European crisis, multivariate GARCH models.

* EconomiX-CNRS, University of Paris Ouest, and Bank of France, Paris, France. Email: henri.audige@u-paris10.fr

1. Introduction

The burst of the sub-prime crisis in 2007 is one of the most traumatic economic incidents of the beginning of the century. This crisis and the economic damages that resulted, notably contributed to the deterioration of the economic outlook and public finances in Europe. The European debt crisis that followed in 2009, distinguishes itself by its intensity; during the crisis, sovereign bond rates in most vulnerable countries such as Greece, Ireland and Portugal more than tripled (Figure 1). Against this backdrop, debt markets tensions progressively spread threatening the economic and financial stability of the whole Euro-area.

Figure 1 – 10 year bond rate in Euro-area main countries



Source: Bloomberg

The European debt crisis (initially known as the Greek debt crisis) started in Greece on the back of higher than expected public deficits and a strong deterioration of the country's economic outlook. Following a succession of general strikes and austerity plans, Greek long term rates progressively rose from 2010 to 2011, peaking to their all-time highest on December 2011 at 33.84. Within that time, the Greek debt had been massively downgraded by major rating agencies, falling into non-investment grade for the first time in April 2010. Greek Bonds and CDS spreads in 2010 and 2011 continued to rise significantly putting the country on the verge of a default by the end of 2011.

On the back of the Greek turmoil, debt market tensions spread progressively to the rest of the Euro-area, reaching first highly indebted countries such as Portugal and Ireland; both countries also witnessed a surge in their long term rates in 2010 and 2011 and saw their sovereign debt rate being progressively downgraded and rated as non-investment grade from July 2011. Tensions on the European debt market climaxed in 2011, on the back of rumors about a possible Greek exit of the European Union, bond spreads soaring in countries initially considered as non-highly indebted and waves of downgrades hitting almost all members of the Euro-area.

With the difficulties encountered by the Greek government at the start of the crisis, uncertainties surrounding a bail-out of Greece and the country's possible exit from the European Union in 2011 remained then a great source of instability. Recent studies (Missio and Watzka, 2011; Constanciô, 2011; Mink and De Haan, 2012) focused on the extent to which the deterioration of the Greek debt situation at the beginning of the crisis did affect the rest of the Euro-area. After estimating dynamic conditional correlation models for government yield spreads of selected Euro-area countries, Missio and Watzka (2011) identify contagion effects from Greece to other Euro-area members (in particular Belgium, Ireland, Portugal and Spain) generated by negative rating announcements in Greece between 2009 and 2010.

Constanciô (2011) proposes two different approaches to investigate contagion effects during the Greek sovereign debt crisis. In his first approach, he uses a state-space representation to perform a multivariate frequency decomposition and shows that high frequency shocks extracted from Greek, Irish and Portuguese bond yields explain bond yield movements in Italy and Spain. In his second approach, Constanciô (2011) relies on a credit risk modeling framework and estimates the effect of an increased probability of a credit event for Greece on the likelihood of a credit event for Portugal and Ireland. His findings show that such contagion effects between Greece and Portugal and Ireland were at play in 2009 and 2011. More recently, Mink and de Haan (2012) perform an event study to analyze the impact of Greek news on Irish, Portuguese and Spanish bond prices during the Greek debt crisis in 2010. They observe that news about both the economic situation in Greece and a Greek bailout have an impact on Irish, Portuguese and Spanish bond rates dynamics, reflecting "wake-up call effects"[1] and not necessarily contagion.

The objective of this paper is to gauge how and to which extent the surge in Greek sovereign bond rates spilled over the rest of the Euro-area. To this end, we rely on a new class of contagion tests based on Smooth Transition Conditional Correlation GARCH models (STCC-GARCH), initially proposed by Silvennoinen and Teräsvirta (2005). In comparison with the usual contagion tests (see Section 2.1), the benefits of this approach are twofold: i) by allowing for regime switches in the dynamics of correlations, it allows to identify more accurately contagion effects following a crisis, ii) the transition variable that governs the regime switching provides both more information about the transition process from one regime to another and a better understanding of the contagion effects during the crisis.

The rest of the paper is organized as follows. In section 2, we briefly review the literature on definitions and tests of financial contagion. In section 3, a test based on a STCC-GARCH model is applied to test for contagion between the Greek and some Euro-area countries bond markets in 2010 and 2011. Section 4 concludes the paper.

2. Financial contagion tests

Contagion is commonly defined in epidemiology as *"the communication of disease from one person or organism to another by close contact"* and primarily refers to the transmission of something *"harmful and corruptive"* due to its closeness.[2] When transposed to the economic sphere, the

1 See Bekaert, Ehrmann, Fratscher and Mehl (2011). Wake-up call occurs when a crisis initially restricted to one country provides new information that may prompt investors to reassess the vulnerability of other countries, because of fundamentals' similarities.

2 See Oxford Dictionaries Online. Some interesting articles such as Edwards (2000) or Bolos et al. (2011) also propose a parallel between financial contagion and contagion in epidemiology literature.

definition of contagion, albeit strongly inspired by the common definition mentioned above, remains vague.

In the mid-1990's, contagion primarily appeared as a dual phenomenon resulting from both macroeconomic and market channels (Calvo and Reinhart, 1996). However, on the back of the successive financial crises in the last decade, alternative definitions of contagion emerged in the literature, stressing differences between fundamentals-based and market-based transmission of crises.

Among the various crisis transmission approaches proposed by the literature, two main definitions emerged, distinguishing (i) contagion or *"pure contagion" (*also called successively *"true contagion"*, *"shift-contagion"* or *"market-based contagion")* and (ii) interdependence comprising "spillovers" and *"monsoonal effects"* and also known as *"fundamentals-based contagion"*.[3]

Billio and Pelizzon (2003) propose however a more restrictive approach, relying on Forbes and Rigobon (2001, 2002) definition stating that "*contagion should be interpreted as the change in the transmission mechanisms that takes place during a turmoil period (…) inferred by a significant increase in the cross-market correlation".* Also, some of the recent literature (Bilio and Caporin, 2005; Chiang et al., 2007) defines contagion as consisting essentially to a structural shift between cross-markets linkages, correlations, co-movements following a shock.

2.1. Correlation-based contagion tests: A brief review

Contagion issues have been covered by a large strand of the empirical literature on market linkages and particularly on excess co-movements in stock market prices. Core studies include those of Shiller (1989), Pindyck and Rotemberg (1990, 1993), Longin and Solnik (1995), and more recently Aslanidis et al. (2009) or Bekaert et al. (2011).

The first tests used in contagion and co-movements studies consisted in the analysis of correlation coefficients between stock market prices.[4] Pindyck and Rotemberg (1990) highlight the existence of co-movements between prices of a sample of commodities initially unrelated, calculating and testing the significance of bivariate correlations among commodity price changes. King and Wadhwani (1994) also focused on financial market linkages and volatility transmission using conditional correlation coefficients to gauge interrelation between international stock markets.

However, in the late 1990's Boyer et al. (1999) followed by Forbes and Rigobon (2002), evidence that misleading conclusions result from the use of conditional correlation coefficients in testing for contagion; these coefficients being upwardly biased in periods of strong volatility. They propose to correct for this bias by using corrected correlation coefficients, finally concluding to the absence of contagion between stock markets during the crisis periods.

Although paving the way to a succession of contagion tests based on correlation techniques, Forbes and Rigobon (2001)'s approach has not been much followed by the literature. This can be explained by misspecification issues (Dungey and Zhumabekova, 2001; Corsetti et al., 2003), as well as the development of correlation techniques such as conditional correlation GARCH models.

3 See Masson (1998), Eichengreen, Rose and Wyplosz (1996), Dornbush et al. (2000), Pericoli and Sbracia (2001), Moser (2003), Pesaran and Pick (2007) and Forbes (2012) for more details on contagion definitions.

4 Beyond correlation-based tests, there are alternative tests for contagion summarized notably by Dungey et al. (2005).

Longin and Solnik (1995) were among the first to use the conditional multivariate distribution of international asset returns in the modeling of cross-markets linkages. They show that international covariance and correlation matrices are unstable over time and test the existence of changes in conditional correlations during turbulent episodes on financial markets for the period 1960-90, using threshold GARCH models. Longin and Solnik (1995) results are furthermore in line with those of King and Wadhwani (1990) and Bertero and Mayer (1990), also stressing the existence of increases in international correlation during stock market crisis periods.

Financial contagion triggers an increase in cross-markets' correlations but may also involve a structural break or a shift in their dynamic. Recent correlation-based tests have tried to assess the time-varying correlation dynamics by using new forms of multivariate GARCH models. The time-varying conditional correlation GARCH (TVCC-GARCH) representation distinguishes itself as a pivotal tool in the modeling and the testing of financial contagion as it permits to easily detect periods of high correlation between observed variables, illustrating contagion effects.

The literature on multivariate GARCH models and time-varying conditional correlations has been significantly growing during the last decade (see Bauwens et al. (2006) and Teräsvirta and Silvennoinen (2007) for a review). More recently, Chiang et al. (2007) use a Dynamic Conditional Correlation GARCH model to test contagion between nine Asian stock returns from 1990 to 2003. Chiang et al. (2007) use dummy variables to delimiting their sample in three periods and, for each period, observe the correlation dynamic between selected stock markets. They detect contagion effects at the beginning of the crisis after the shock in Thailand with a surge in markets correlations, followed by a phase of "herding behavior" during which investors' behaviors tend to converge and correlations among the observed stock markets remain high.[5] However, the use of dummy variables to model structural changes in the dynamic of conditional correlations may lead to accuracy issues concerning the duration of the crisis, and models taking into account endogenously shifts in the correlation structure may thus be preferred.

Although not using a multivariate GARCH model, Yang et al. (2009) come to the same conclusion when modeling stock-bond correlations for US and UK over a century and half (from 1855 to 2001). Following an approach initially developed by Silvennoinen and Teräsvirta (2005) in a multivariate GARCH framework, the authors analyze conditional correlations using a bivariate AR (1)-GARCH (1, 1) model and augment the latter with smooth transition conditional correlations (conditional correlations are constant in each regime, and changes in conditional correlations from a regime to another are modeled with a gradual transition function).

2.2. Contagion testing with a STCC-GARCH model

2.2.1. The model

In this paper, we follow the multivariate STCC-GARCH approach proposed by Silvennoinen and Teräsvirta (2005, 2009). The conditional correlation matrix P_t is modeled as follows

$$P_t = (1 - g_t)\, P_{(1)} + g_t\, P_{(2)} \qquad (1)$$

Where $P_{(1)}$ and $P_{(2)}$ are positive definite correlation matrices and g_t is a scalar transition function whose values are bounded between 0 and 1. Conditional correlations are assumed to change

5 Min and Hwang (2011) and Kazi et al. (2011) also obtain similar results in their test of contagion using a DCC-GARCH model.

smoothly over time depending on one and two transition variables. Time-varying correlation structures are modeled using a first order logistic function

$$g(s_t ; \gamma, c) = (1 + \exp\{- \gamma (s_t - c)\})^{-1} \quad (2)$$

with γ > 0 is the slope parameter, s_t is the transition variable and the parameter *c* can be interpreted as the threshold between the two regimes; the function changing monotonically from 0 to 1 as s_t increases. For s_t = c the logistic function, g(s_t; γ, c) becomes equal to 0.5. For $s_t < c$ the correlations are closer to the lower state, while for $s_t > c$ the situation is the opposite. The parameter γ corresponds to the speed of the transition and controls the smoothness of the transition between the two states. For γ close 0 the transition is slower, while for $\gamma \to \infty$, the transition function becomes a step function, and the switch from a regime to another becomes abrupt.

2.3.2. Constancy test

As suggested by Silvennoinen and Teräsvirta (2009), parametric modeling of conditional correlations must begin with testing the constancy of correlations. Silvennoinen and Teräsvirta (2005) propose a LM-type test of constant conditional correlation against a STCC-GARCH alternative.

It is necessary to carefully select an appropriate transition variable as a failure to reject the constancy of correlations implies that the chosen transition variable does not explain the time-varying structure of the correlations. However, would the null hypothesis of the test be rejected, this could be interpreted as evidence of non-constancy of conditional correlation and would imply that the transition variable carries information about the structure of the correlations. In order to derive their test, Silvennoinen and Teräsvirta (2005) consider an N-variate case to test the assumption of constant conditional correlations against time-varying conditional correlations with a simple transition function (see Equations (1) and (2)).

For simplicity, we assume that the conditional variance of each of the individual series follows a GARCH (1, 1) process. The STCC-GARCH model falls into a constant correlation model under the null hypothesis of γ = 0 in (2). When this restriction holds, however, some of the parameters of the model are not identified. To circumvent this problem, Silvennoinen and Teräsvirta (2005) suggest to follow Luukkonen, Saikkonen, and Teräsvirta (1988) and to consider an approximation of the alternative hypothesis. It is obtained by a first-order Taylor approximation around γ = 0 to the transition function G_t:

$$G(s_t ; \gamma, c) = (1 + \exp\{- \gamma (s_t - c)\})^{-1} = ½ + (¼) (s_t - c) \gamma \quad (3)$$

Once linearized the time-varying conditional correlation matrix P_t^* is

$$P_t^* = P_{(1)}^* + s_t P_{(2)}^* \quad (4)$$

where

$$P_{(1)}^* = ½ (P_{(1)} + P_{(2)}) + ¼\, c\, (P_{(1)} - P_{(2)})\, \gamma,$$
$$P_{(2)}^* = ¼ (P_{(1)} - P_{(2)})\, \gamma.$$

If γ = 0 and $P_t^*(2) = 0$, then the correlations are constant.[6]

6 For more details on the LM-type constancy test, see Silvennoinen and Teräsvirta (2005).

Contrary to Markov-switching approaches, the STCC-GARCH approach allows correlation regimes to be modeled as a function of a transition variable. Given high or low levels of the transition variable, conditional correlation will then switch from a regime to the other. The speed of the switches between regimes is assessed by the speed parameter γ, while the location parameter gives the level of the transition variable triggering the shift in correlation regimes.

In addition, the modeling of regimes through a transition function improves the previous contagion tests relying on correlation-based models, such as DCC-GARCH or MS-DCC-GARCH, in the extent that it provides a better and more accurate determination of contagion periods following a shock.[7]

3 Empirical application: the Greek case

3.1 Data

We focus on the links between Greek 10-year bond rates and those of the main Euro-area countries. Our data set is then composed of daily 10-year benchmark government bond rates for France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal and Spain (source: Bloomberg). Our two transition variables are: (i) the 10-year Greek bond rate and (ii) the EURO STOXX 50 volatility index, denoted as VSTOXX (source: Bloomberg), which reflects the implied volatility on the European stock index and is a good proxy for market risk aversion (see Figure 2 in the Appendix).

Retaining these two transition variables allows us to investigate whether the dynamic of conditional correlations between Greek and our selected countries' bond rates can be explained by either changes in the Greek long term rates or rather results from European markets' volatility. The choice of Greek bond rate as the transition variable relies on the assumption that economic changes specific to Greece may influence bond rates correlations between Greece and other countries of the Euro-area. The choice of the VSTOXX as the transition variable allows us to gauge to which extent markets' risk aversion, through effects not directly related to Greek fundamentals, explains the correlation structure between Greek rates and those of our selected countries.

Two time periods are considered. The first one goes from January 5th to December 30th 2010, while the second period starts on January 1st 2011 and ends in October 10th 2011.[8] These periods include strong volatility episodes on the Greek debt market in late April 2010 and end 2011; Greek bond rates peaking at their highest level in April 2010 on the back of economic and social tensions in the country, and markets tensions being concentrated in September on the back of accrued volatility on financial markets in 2011 (see Figure 3 and 4 in the Appendix).

In 2010, debt markets tensions triggered a succession of austerity measures and announcements of the newly elected Greek prime Minister at the time, Georges Papandreou, on the back of a drastic reduction of the Greek public deficits for 2012. These measures have been then followed by several waves of general strikes in March, reflecting fears of a deterioration of the social and economic outlook in the country. The Greek situation on the debt market also worsened when Fitch, Moody's, and Standard and Poor's successively downgraded the Greek debt rating between April 9th and April 27th by one notch each (from BBB+ to BBB-, from A2 to A3, and from BBB+ to BB+ respectively).

[7] Our estimation procedure was applied using Ox programs supplied by Annastiina Silvennoinen.

[8] Due to accrued tensions on the Irish bond markets, Irish 10-year rates stopped to be traded in October 11th 2011, for practical reasons we keep the same data sample for all our series. Moreover, the reducing of our data sample does not affect our test conclusions in 2011.

On May 2nd 2010, as a support to the Greek Government, Euro-area Member States agreed on a three year program providing a total of EUR 80 billion in bilateral loans, followed by the IMF with a stand-by agreement of EUR 30 billion. To curb possible contagion risks in the Euro-area, European authorities then created on May 9th 2010 the European Financial Stability Facility (EFSF).[9] Within that time, Greek bond rates rose to 12% in May 7th 2010, doubling their January level. Following the Greek debt market deterioration, Ireland, Portugal and Spain—though better rated than Greece—also saw their ratings downgraded, these downgrades raising then fears of a broad wave of contagion over the whole Euro-area. When observing bond rates volatility levels, the Greek shock-wave have had a significant impact on all the other countries of the Euro-area (see Figure 3), our selected countries' bond rates posting a volatility peak in May 2010.

The 2011 period is characterized by a worsening of financial markets conditions, on the back of the Greek rate's downward spiral; Moody's downgrading the Greek debt three times between March and September 2011 (from Ba1 to Ca), Standard and Poor's four times (from BA+ to CC) and Fitch twice from BB+ to CCC. Contagion fears are also on the rise, as Irish, Portuguese and Spanish ratings are significantly downgraded. Following the downgrade of the US debt on August 5th 2011 for the first time in history, threats of a downgrade of Euro-area “core countries” such as France, emerge.

3.2 Constancy tests and Estimation results

3.2.1 Constancy tests

Through the use of constancy tests, we are able to determine whether the transition variable evolution explains the change in conditional correlations between Greek and our selected countries bond rates. Using Greek bond rates as the transition variable, no changes in correlations are observed except for Italy and Spain in 2010 and for peripheral countries in 2011 (Ireland, Portugal and Spain). Markets’ volatility in Europe (using the VSTOXX as transition variable) explains changes in correlation for all countries except Italy and Spain in 2010 and France and Portugal in 2011 (see Table 1 and 2 in the Appendix).

Constancy results give us an interesting hint concerning possible crisis transmission effect. Indeed, correlation changes explained by markets’ volatility or changes in the Greek rate dynamic in 2010 and 2011 probably reflect flight-to-quality and or contagion effects from Greece to the rest of the Eurozone. STCC-GARCH estimations results should permit to define more precisely the nature of our correlations and confirm the possible effects suggested by our constancy tests.

3.2.2 Estimation results with the Greek 10-Year bond rate as the transition variable

We observe a drop in correlations for Italy and Spain following the significant increase in Greek rates in April 2010. The downward shift observed in conditional correlations primarily reflected the “market awareness effects” highlighted by Afonso et al. (2011), who explain the drop in euro-area bond rates correlation by a reversal in market investors' stance vis-à-vis the European sovereign bond market during the crisis. According to Afonso et al. (2011), such a reversal primarily results from an increased awareness of macro and fiscal fundamentals in Euro-area countries from investors who finally tend to discriminate countries of the Euro-area according to their macroeconomic background and indebtedness level (see Table 3 in the Appendix).

---

9 For more details on the EFSF see the European commission webpage : http://ec.europa.eu/economy_finance/focuson/crisis/2010-04_en.htm

Changes in correlation levels for Spain following April tensions on the Greek debt market were however temporary, correlations moving back to their previous level for both country groups in May 2010. This move primarily stemmed from a rise in markets confidence after the agreement reached by Greece with Troïka (i.e. the International Monetary Fund, the European Central Bank (ECB) and the European Commission) on a stabilization program of EUR 110 bln to support the Greek economy. Correlations however dropped back following a downgrade of the Greek debt rating by Moody's in mid-June 2010 (see Figure 5 in the Appendix).

Spanish correlations dropped significantly early in September 2011 probably reflecting once again “markets’ awareness effects”; the Spanish parliament having agreed September 7th to enclose a Golden rule in the Spanish constitution to mitigate concerns over public finances. Irish and Portuguese correlations dropped significantly in 2011 suggesting also “markets’ awareness effects” both countries benefiting in the end of July 2011 from the EU/FMI Assistance Programs and being hence sheltered from accrued market tensions on their debt market (see Figure 6 in the Appendix).

All in all, conditional correlation between Greece and other highly indebted peripheral countries were relatively high in 2010 and progressively decreased from 2010 to 2011. The surge in Greek bond rates witnessed during these periods explains this drop in correlations as markets become aware of the divergences of fundamentals between peripheral. In the first time of the crisis, “markets’ awareness” effects appear in Italy and Spain, correlations between Greece and both countries dropping significantly, public deficit issues in Spain and Italy being considered as not as strong as in Greece.

The same phenomenon appear once again in 2011, for Spain, Ireland and Portugal, correlations with Greece further decreasing, markets this time fully integrating the disconnection between Greek and the other peripheral countries’ fundamentals.

3.2.3 Estimation results with the VSTOXX as the transition variable

Correlation levels for Ireland and Portugal significantly increase in 2010 after the strong rise in Greek bond rates of April 27th. The sensitivity of Irish and Portuguese correlations to market risk aversion as transition variable probably reflects both contagion and “wake-up call” effects during this period: contagion as we observe a significant correlation increase in both countries following a shock on the Greek bond market, and a “wake-up call” effect as following April's Greek shock, we observe a strong rise in both Irish and Portuguese correlations explained by an increase in markets aversion (see Table 2 in the Appendix).

The “wake-up call” effect was somewhat mild in the Portuguese case; the outlook on the Portuguese debt rating being already negative for markets in the end of 2009 and the country having witnessed a downgrade of its debt rating by Fitch’s by one notch from to AA- in March 2010. However, the wake-up call fully operated for Ireland, the country only witnessing tensions in its debt market later in July 2010 with a downgrade of its sovereign bond by Moody’s from by one notch to Aa2.

With rising markets’ tension in the end of April 2010, we observe a sharp drop in conditional correlation for core countries, primarily suggesting “flight to quality” effects to these countries and reflecting markets’ confidence towards their debt prospects in 2010. This drop in correlations furthermore reflects the importance of core countries as safe haven, Germany being naturally perceived as the main safe haven of the Euro-area after the peak in markets’ volatility (see Figure 7 in the Appendix).

The correlation pattern however changed in 2011. Indeed, although remaining negative, German and Dutch correlations increase on the back of rising tensions on European debt markets, notably with rumors of a downgrade of the French sovereign debt early August, rising uncertainties about a Greek bail-out, threats of a possible exit of the Greece from the Euro-area and the collapse of the Euro that may follow.

Correlations for Ireland, Italy and Spain dropped from early August in 2011, on the back of the the Intervention of the ECB on markets Spanish and Italian debt markets through the Securities Markets Program (SMP). Hence, on August 7th 2011, the ECB purchased significant amounts of Italian and Spanish government debt, bringing about a drop in their benchmark 10-year rates and alleviating temporarily market pressures on their debt markets (See Figure 8 in the Appendix).

4. **Conclusion**

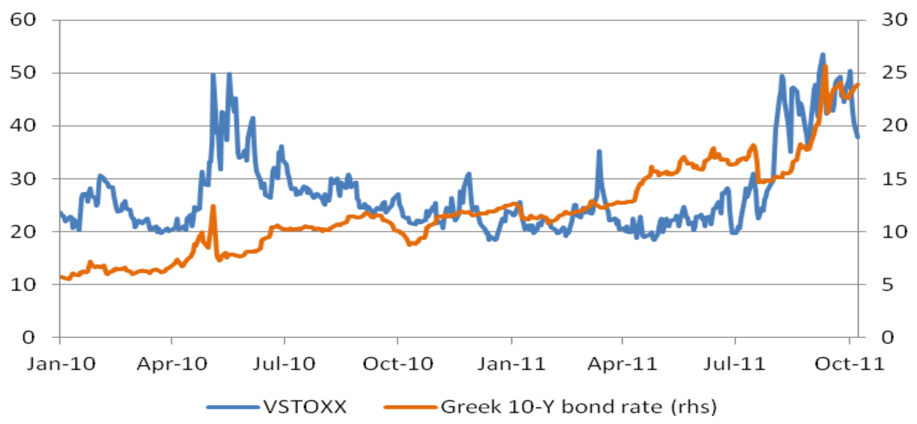
The aim of this paper was to identify contagion effects from Greece to other countries of the Euro-area following surges in market tensions in 2010 and 2011. To this end, we rely on the STCC-GARCH framework to model correlations between sovereign bonds of Greece and other Euro-area countries and take into account shifts between the different correlation regimes.

Our results confirm the existence of contagion and “wake-up call” effects from Greece limited to Ireland and Portugal in 2010. Other phenomena such as “markets’ awareness” or “flight-to-quality” effects also emerge, illustrating the way the Greek debt shock and markets’ tensions on sovereign debt markets diversely affected Euro-zone countries in 2010 and 2011. In line with those results, Caporin et al. (2012) highlight the radical change in markets perception towards the Euro-zone sovereign bonds after 2009 and show that transmission effects following specific shocks remain limited (as in our case only Ireland and Portugal witnessed a contagion effects on their respective sovereign debt market).

In determining precisely when the correlation shift occurs, the STCC-GARCH framework provides a more accurate modeling of changes in the structure of correlations and a better overview of contagion phenomena. Silvennoinen and Teräsvirta (2009) introduced a Double Smooth Transition Conditional Correlation (DSTCC) GARCH model, where changes in the correlations structure are explained by two transition variables. Beyond the STCC-GARCH, measuring contagion with a DSTCC-GARCH may give more room for interpretation of correlation changes, which is left for future research on contagion.

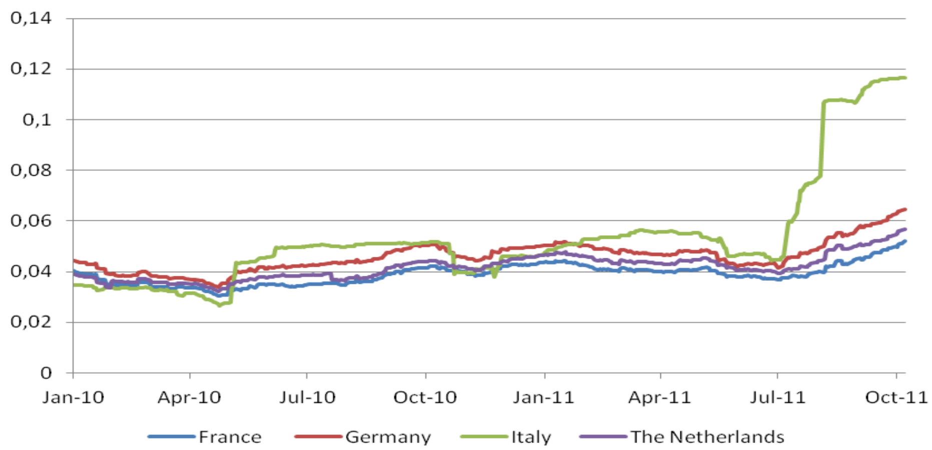
5. Appendix

Figure 2 – The VSTOXX and the Greek 10-year bond rate from 2010 to 2011



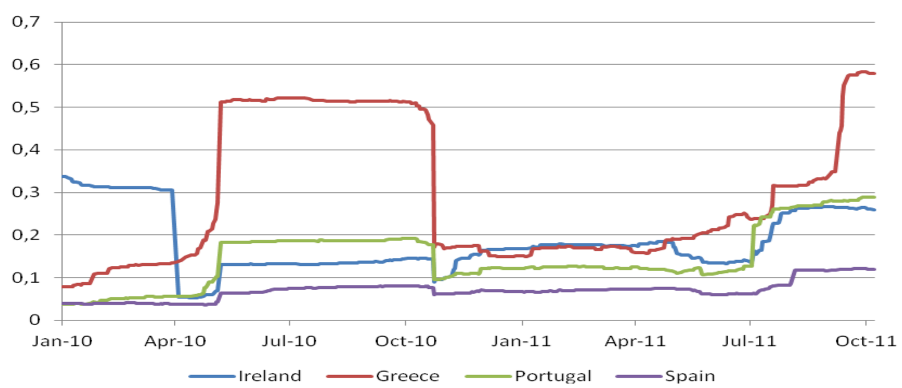
Source: Bloomberg

Figure 3 – Core countries bond rates volatility (6-month rolling standard deviation) from 2010 to 2011



Source: Bloomberg

Figure 4 - Peripheral countries bond rates volatility (6-month rolling standard deviation) from 2010 to 2011



Source: Bloomberg

Table 1 – p-values of the constancy test and STCC-GARCH estimates with Greek bond rates and the VSTOXX as transition variables in 2010 (standard errors in parentheses)

	p-value	*P1*	*P2*	*threshold parameter*
With the Greek bond rate				
Core countries:				
France	0.46194	-	-	-
Germany	0.32645	-	-	-
The Netherlands	0.97359	-	-	-
Italy	0.075864	0.61758 (0.075127)	0.32431 (0.062403)	7.3593
Peripheral countries:				
Ireland	0.13891	-	-	-
Portugal	0.12971	-	-	-
Spain	0.036455	0.63589 (0.061842)	0.37548 (0.065033)	8.1222
With the VSTOXX				
Core countries:				
France	0.027152	0.10441 (0.072004)	-0.078289 (0.093024)	26.5
Germany	0.020304	0.0046734 (0.074314)	-0.32059 (0.085654)	28.365
The Netherlands	0.018704	0.077894 (0.073723)	-0.11851 (0.081148)	26.5
Italy	0.32429	-	-	-
Peripheral countries:				
Ireland	0.0034527	0.49125 (0.062853)	0.64295 (0.050636)	26.541
Portugal	0.041619	0.51121 (0.053470)	0.77656 (0.042593)	29.029
Spain	0.82706	-	-	-

Note: Countries without correlation estimates for P1, P2 and c are countries for which the transition variable does not explain the regime changes between correlation levels.

Table 2 – p-values of the constancy test and STCC-GARCH estimates with Greek bond rates and the VSTOXX as transition variables in 2011 (standard errors in parentheses)

	p-value	*P1*	*P2*	*threshold parameter*
With the Greek bond rate				
Core countries:				
France	0.22273	-	-	-
Germany	0.15880	-	-	-
The Netherlands	0.26128	-	-	-
Italy	0.20179	-	-	-
Peripheral countries:				
Ireland	1.7330e-005	0.69517 (0.060752)	0.25803 (0.11379)	15.870
Portugal	0.0015601	0.78568	0.28303 (0.063675)	15.208
Spain	0.0044360	0.41427 (0.063869)	0.16086 (0.10716)	20.195
With the VSTOXX				
Core countries:				
France	0.28926	-	-	-
Germany	0.0063808	-0.37984 (0.085141)	-0.066452 (0.084956)	35.140
The Netherlands	0.014819	-0.13669 (0.059541)	-0.0049935 (0.060075)	28.862
Italy	0.0030377	0.41306 (0.070723)	0.21298 (0.071754)	28.709
Peripheral countries:				
Ireland	2.8419e-007	0.56125 (0.057735)	0.12600 (0.10100)	27.901
Portugal	0.16569	-	-	-
Spain	8.9716e-005	0.52525 (0.060549)	0.18577 (0.090533)	36.779

Note: Countries without correlation estimates for P1, P2 and c are countries for which the transition variable does not explain the regime change between correlation levels.

Figure 5 - STCC-GARCH conditional correlation estimates with Greek bond rates as transition variable in 2010

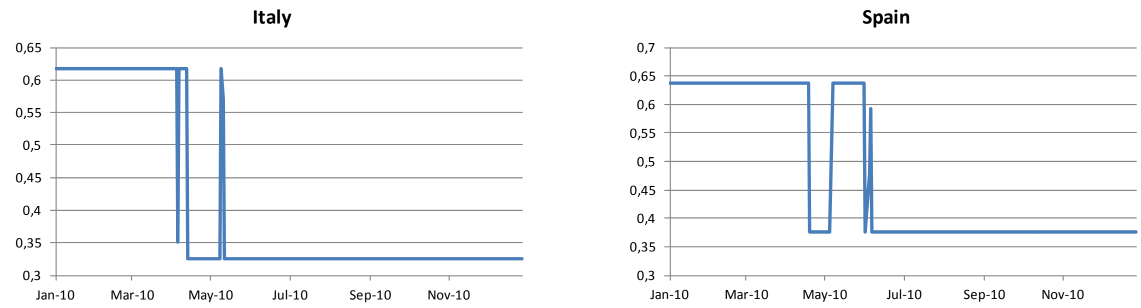


Figure 6 - STCC-GARCH conditional correlation estimates with Greek bond rates as transition variable in 2011

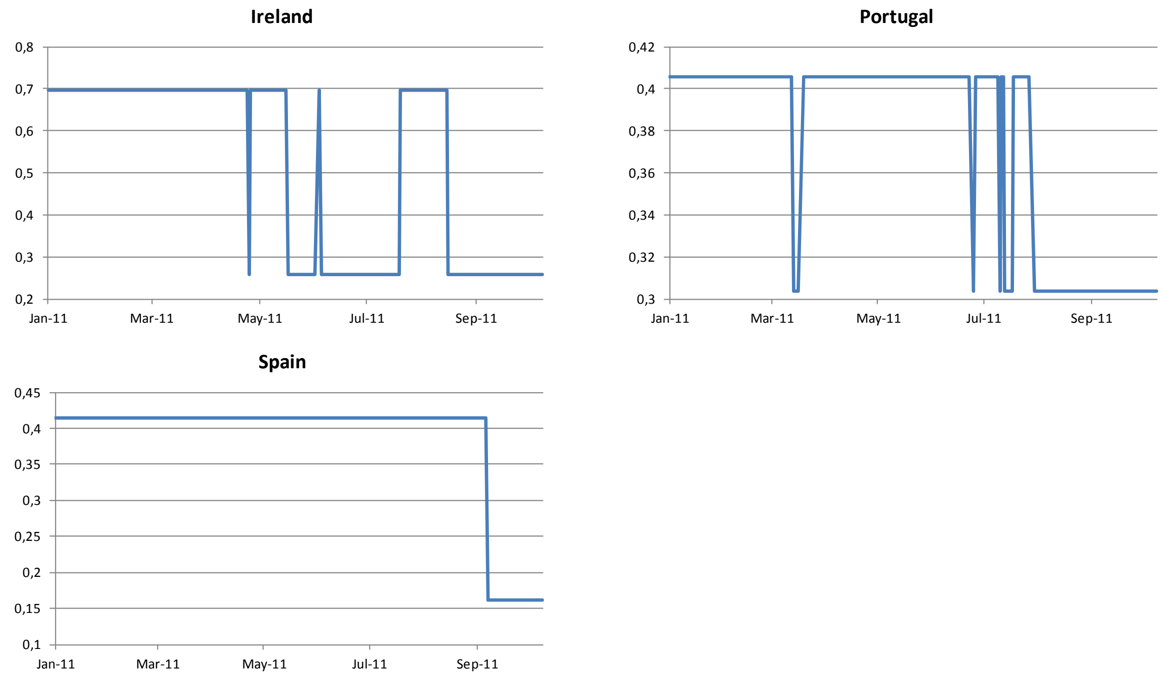


Figure 7 - STCC-GARCH conditional correlation estimates with the VSTOXX as transition variable in 2010

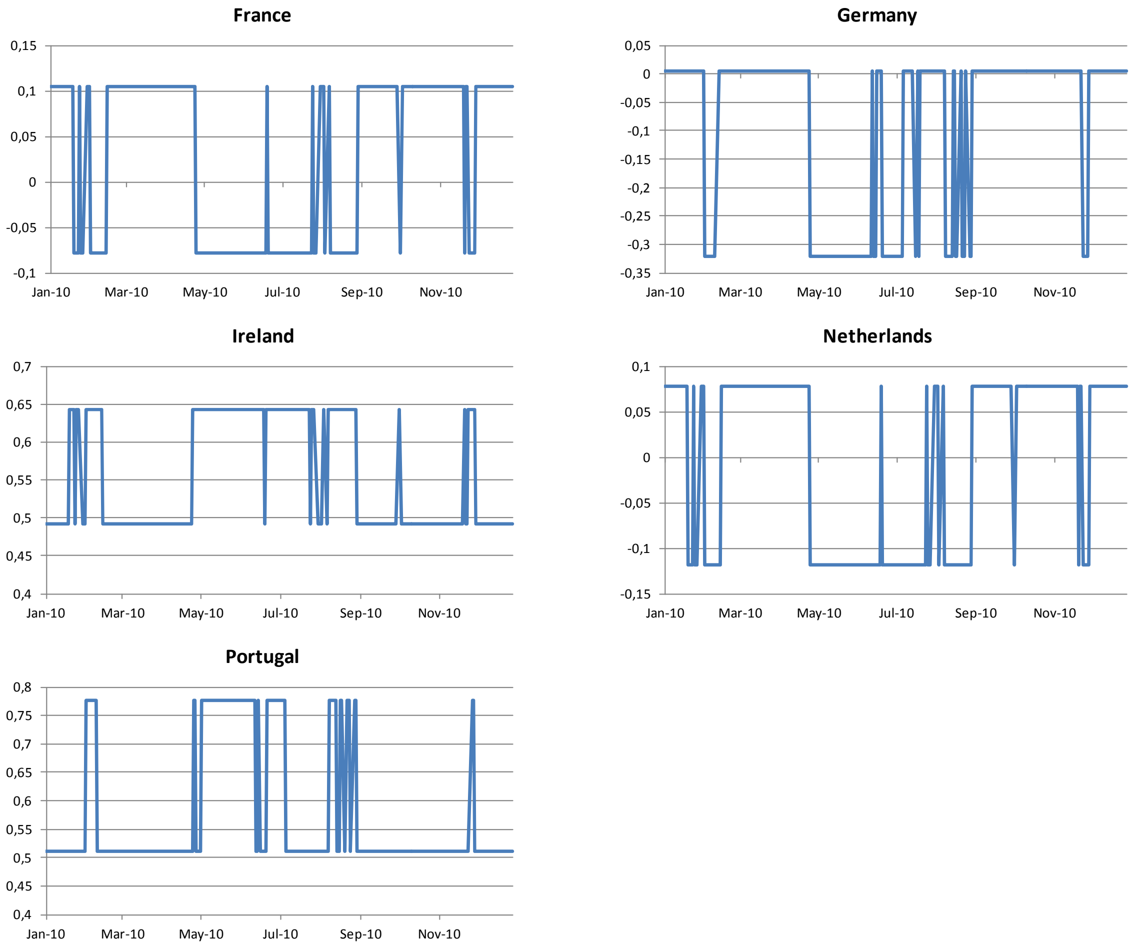
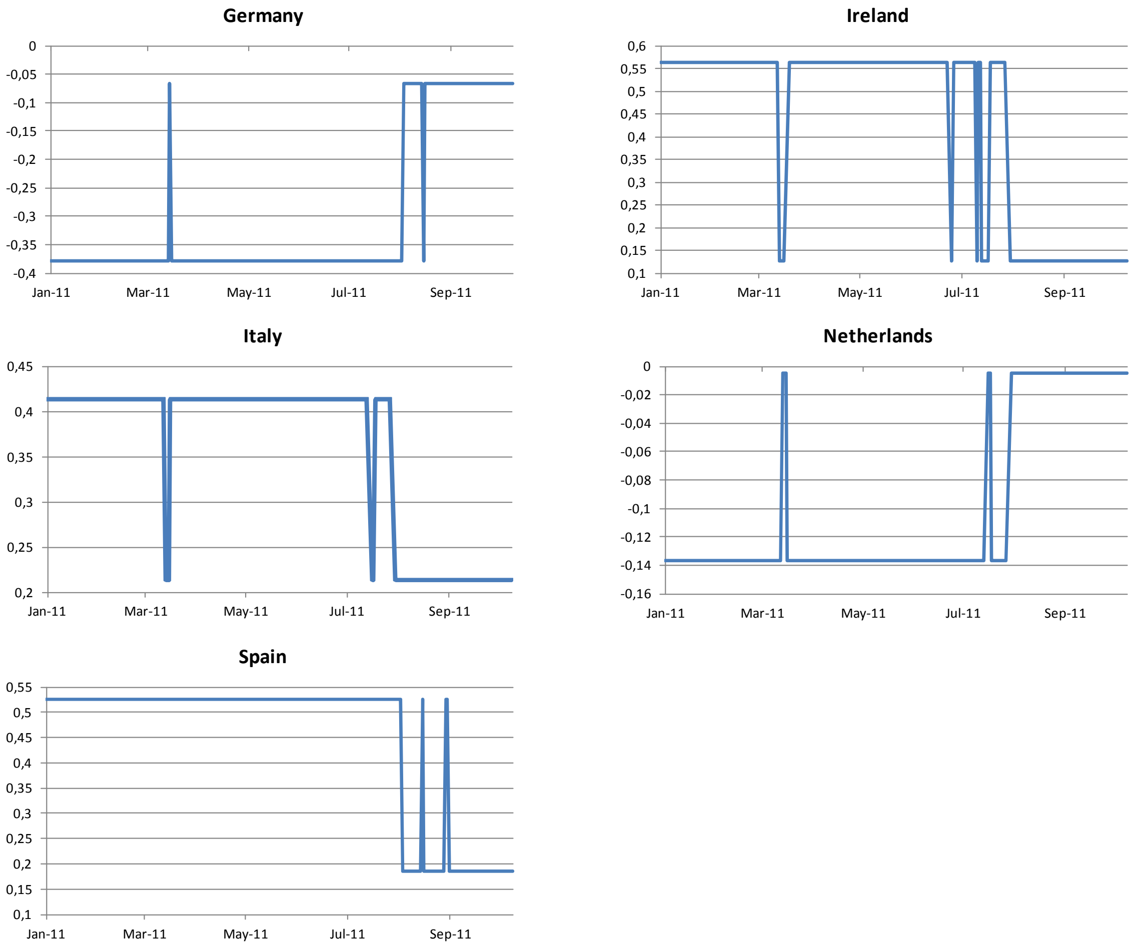


Figure 8 - STCC GARCH Conditional correlation estimates with the VSTOXX as transition variable 2011



6. Bibliography

Afonso A., D. Furceri and P. Gomes, 2011. “Sovereign Credit Ratings and Financial Makets Linkages”. ECB, Working Paper 1347.

Aslanidis N, D.R. Osborn and M. Sensier, 2008. "Co-movements between US and UK stock prices: the roles of macroeconomic information and time-varying conditional correlations," Centre for Growth and Business Cycle Research Discussion Paper Series 96, Economics, The Univeristy of Manchester.

Bauwens, L., S. Laurent, & J.K. Rombouts, 2006. “Multivariate garch model : a survey”, Journal of Applied Econometrics, 21 (1), 79-109.

Bekaert G., M. Ehrmann, M. Fratzscher and A.J. Mehl, 2011. "Global Crises and Equity Market Contagion", NBER Working Papers 17121.

Bertero E. and C. Mayer, 1990. “Structure and Performance: Global interdependence of stock markets around the crash of October 1987”. European Economic Review-34(1990) 1155-1180.

Billio, M. and M. Caporin, 2005. “Multivariate Markov switching dynamic conditional correlation GARCH representations for contagion analysis”, Statistical Methods and Applications, 14/2, 145-161.

Billio M. and L. Pelizzon, 2003. "Contagion and interdependence in stock markets: Have they been misdiagnosed?," Journal of Economics and Business, Elsevier, vol. 55(5-6), pages 405-426.

Bolos B., V. Bacârea and M. Marusteri, 2011.“Approaching economic issues through epidemiology - an introduction to business epidemiology. Romanian Journal of Economic Forecasting, 1, 257-276.

Boyer B.H., M.S. Gibson and M. Loretan, 1999. “Pitfalls in tests for changes in correlations”. Board of Governors of the Federal Reserve System - International Finance Discussion Papers.

Calvo, G. & Reinhart, C., 1996. Capital inflows to Latin America: Is there evidence of contagion effects? Policy Research Working Paper 1619, World Bank.

Caporin M., L. Pelizzon, F. Ravazzolo, and R. Rigobon, 2012. “Measuring Sovereign Contagion in Europe”, CAMP Working Paper Series, No. 4/2012

Chiang T.C., J. Bang Nam and L. Huimin, 2007. "Dynamic correlation analysis of financial contagion: Evidence from Asian markets," Journal of International Money and Finance, Elsevier, vol. 26(7), pages 1206-1228, November.

Constanciô, V., 2012. “Contagion and the European debt crisis”. Bank of France, Financial Stability Review, (16), 109-121.

Corsetti G., M. Pericoli and M. Sbracia, 2002. "Some Contagion, Some Interdependence: More Pitfalls in Tests of Financial Contagion," CEPR Discussion Papers 3310, C.E.P.R. Discussion Papers.

Dornbusch R., Y. Chul Park and S. Claessens, 2000. “Contagion: Understanding: How It Spreads”. The World Bank Research Observer, vol. 15, no. 2 (August 2000), pp. 177–97.

Dungey M. and R. Fry, B. Gonzalez-Hermosillo and V. Martin, 2005. "Empirical modelling of contagion: a review of methodologies," Quantitative Finance, Taylor and Francis Journals, vol. 5(1), pages 9-24.

Dungey M. and D.Zhumabekova, 2001. "Testing for contagion using correlations: some words of caution," Pacific Basin Working Paper Series 01-09, Federal Reserve Bank of San Francisco.

Edwards, S., 2000. "Contagion", University California Los Angeles and National Bureau of Economic Research.

Eichengreen B., A.K. Rose and C. Wyplosz, 1996. "Contagious Currency Crises," CEPR Discussion Papers 1453, C.E.P.R. Discussion Papers.

Forbes K.J., 2012. "The Big C; identifying and mitigating contagion", MIT-Sloan School of Management.

Forbes K.J. and R. Rigobon, 2001. "Contagion in Latin America: Definitions, Measurement, and Policy Implications," Journal of LACEA Economica, LACEA.

Forbes K.J. and R. Rigobon, 2002. "No Contagion, Only Interdependence: Measuring Stock Market Comovements," Journal of Finance, American Finance Association, vol. 57(5), pages 2223-2261, October.

Hwang Y.-S. and H.-G. Min, 2011. "Dynamic Correlation Analysis of US Financial Crisis and Contagion: Evidence from Four OECD countries".

Kazi I., A., and K. Guesmi and O. Kaabia, 2011. "Contagion Effects of Financial Crisis on OECD Stock Makets". Open-Assessement E-Journal, Discussion Paper. No 2011-15.

King M. and E. Sentana and S. Wadhwani, 1994. "Volatility and Links between National Stock Markets," Econometrica, Econometric Society, vol. 62(4), pages 901-33, July.

King, M. and S. Wadhwani, 1990. "Transmission of Volatility between Stock Markets," Review of Financial Studies, Oxford University Press for Society for Financial Studies, vol. 3(1), pages 5-33.

Longin F. and B. Solnik, 1995. "Is the correlation in international equity returns constant: 1960-1990?". Journal of International Money and Finance, Vol. 14, No. 1, pp.3-26.

Luukkonen R. and P. Saikkonen and T. Teräsvirta, 1988. "Testing linearity against smooth transition autoregressive models", Biometrika, 75(3), 491-499.

Masson P.R., 1998. "Contagion-Monsoonal Effects, Spillovers, and Jumps Between Multiple Equilibria," IMF Working Papers 98/142, International Monetary Fund.

Mink M. and J. de Haan, 2012. "Contagion during the Greek Sovereign Debt Crisis," DNB Working Papers 335, Netherlands Central Bank, Research Department.

Missio S. and S. Watzaka. (2012). Financial Contagion and the European Debt Crisis. Working Paper 3554, CESifo.

Moser T., 2003. “What Is International Financial Contagion”. International Finance 6:2, 2003: pp.157-178.

Pesaran M. and A. Pick, 2007.”Econometric issues in the analysis of contagion”, Economic Journal, Royal Economic Society, 31(4), 1245-1277 .

Pericoli M. and M. Sbracia, 2001. "A Primer on Financial Contagion," Temi di discussione (Economic working papers) 407, Bank of Italy, Economic Research and International Relations Area.

Pindyck R.S and J.J. Rotemberg, 1990. "The Excess Co-movement of Commodity Prices," Economic Journal, Royal Economic Society, vol. 100(403), pages 1173-89.

Schiller R., 1989. “Comovements in stock prices and comovements in dividends”, NBER Woking Paper 2846.

Silvennoinen A. and T. Teräsvirta, 2005. "Multivariate Autoregressive Conditional Heteroskedasticity with Smooth Transitions in Conditional Correlations," Working Paper Series in Economics and Finance 577, Stockholm School of Economics.

Silvennoinen A. and T. Teräsvirta, 2007. "Multivariate GARCH models," Working Paper Series in Economics and Finance 669, Stockholm School of Economics.

Silvennoinen A. and T. Teräsvirta, 2009. "Modeling Multivariate Autoregressive Conditional Heteroskedasticity with the Double Smooth Transition Conditional Correlation GARCH Model," Journal of Financial Econometrics, vol. 7(4), pages 373-411.

Yang J., Y. Zhou and Z. Wang, 2009. “The stock-bond correlation and macroeconomic conditions: One and half centuries of evidence”. Journal of Banking and Finance 33 (2009) 670-680.