A new approach of contagion based on STCC-GARCH models: An empirical application to the Greek crisis

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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, G10, G12

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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 (see Figure 1). Against this backdrop, debt markets tensions progressively spread threatening the economic and financial stability of the whole Euro-area.

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 & Watzaka (2012); Constanciô (2012); Mink & 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 & Watzaka (2012) 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 (2012) 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 (2012) 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 & 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 & Teräsvirta (2005) and a Double Smooth Transition Conditional Correlation GARCH (DSTCC-GARCH), which is a augmented STCC-

[1] See Bekaert et al. (2006). 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.

GARCH with transition variable introduced by Silvennoinen & Teräsvirta (2009). 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-and DSTCC-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 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 & 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,

[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.

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 & Pelizzon (2003) propose however a more restrictive approach, relying on Forbes & Rigobon (2001) and Forbes & Rigobon (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 (Billio & Carporin (2006); 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 Schiller (1989), Pindyck & Rotemberg (1990), Longin & Solnik (1995) and more recently Aslanidis et al. (2008) orBekaert et al. (2006).

The first tests used in contagion and co-movements studies consisted in the analysis of correlation coefficients between stock market prices.[4] Pindyck & 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 et al. (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 & Rigobon (2002), evidence that misleading conclusions

[3] See Masson (1998), Eichengreen et al. (1996), Moser (2003), Pesaran & 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).

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 & Rigobon (2001)'s approach has not been much followed by the literature. This can be explained by misspecification issues (Dungey & Zhumabekova (2001); Corsetti et al. (2012)), as well as the development of correlation techniques such as conditional correlation GARCH models. Longin & 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 & Solnik (1995) results are furthermore in line with those of King & Wadhwani (1990) and Bertero & 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 **?** and Silvennoinen & Teräsvirta (2008) 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 & 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- and a DSTCC - GARCH model

In their paper, Silvennoinen & Teräsvirta (2005) rely on a GARCH model where conditional correlations are allowed to be time-varying[6]. Time-varying conditional correlations are modeled through a Smooth Transition Conditional Correlation GARCH (STCC-GARCH) model. The conditional correlations are assumed to change smoothly between two extreme states of nature with state-specifid constant correlations among variables. Changes

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

[6] see Silvennoinen & Teräsvirta (2005) for a specification in details of the general multivariate GARCH model used before modeling time-varying conditional correlations

of correlation between theses states are modeled as a function of a transition variable.The conditional correlation matrix is then defined as[7]

$$P_t = (1 - G_t)P_1 + G_t P_2 \quad (1)$$

Where P_1 and P_2 are positive definite correlation matrices and G_t is a transition function whose values are bounded between 0 and 1. Conditional correlations are assumed to change smoothly over time depending on one 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 $\gamma > 0$, the slope parameter, also corresponding to the speed of transition, s_t, the transition variable, c, the location of the transition, or the shift-point between the two regimes of correlation; the function changing monotonically from 0 to 1 as s_t increases. For $s_t = c$ the logistic function, $G(s_t; \gamma, c)$ 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 is a step function, and the switch from a regime to another becomes abrupt.

Silvennoinen & Teräsvirta (2009) propose an extension of the STCC-GARCH model, the Double Smooth Transition Conditional Correlation GARCH model (DSTCC-GARCH) where conditional correlations vary this time according to two transition variables. The time-varying correlation structure for this new model is imposed through the following equations:

$$P_t = (1 - G_{1t})P_{(1)t} + G_{1t}P_{(2)t}, \;\; P_{(i)t} = (1 - G_{1t})P_{(1)}t + G_{1t}P_{(2)t}, i = 1, 2, \quad (3)$$

[7]For more details on the specification of P_t see Silvennoinen & Teräsvirta (2005).

where the transition function is still a logistic function

$$G_{it} = (1 + exp\{-\gamma_i(s_{it} - c_i)\})^{-1}, \gamma_i > 0, i = 1, 2, \quad (4)$$

and s_{it}, $i = 1, 2$, are transition variables.

Before the modeling of conditional correlations, we first implement a LM-type test of constant conditional correlation against a STCC-GARCH and against a DSTCC-GARCH alternative proposed respectively bySilvennoinen & Teräsvirta (2005) and Silvennoinen & Teräsvirta (2009). In both case, it is necessary to carefully select the appropriate transition variables, as a failure to reject the constancy of correlations implies that the chosen variables do 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 variables carry information about the structure of the correlations. The STCC-GARCH and DSTCC-GARCH models fall into a constant correlation model under the null hypothesis when the slope of the selected transition variables is null, (i.e. $\gamma_1 = 0$ and $\gamma_2 = 0$ in 4).[8]

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.[9] Our data set is then composed of daily 10-year benchmark government bond rates for France, Germany, Greece, Ireland,

[8]When this restriction holds some of the parameters of the model are however not identified. To circumvent this problem, see Silvennoinen & Teräsvirta (2005) and Silvennoinen & Teräsvirta (2009)

[9]Several studies on contagion, such as Caporin et al. (2013) rely on the analysis of contagion in the euro area using sovereign CDS spreads. However, as shown by Coudert & Gex (2010) the role played by CDS markets in the price discovery process in the European sovereign debt markets remains weak concerning euro-area core countries and peripheral countries in a lesser extent (see also Fontana & Scheicher (2010) and Delatte et al. (2012)).

Italy, the Netherlands, Portugal and Spain. Our three transition variables are: *a)* the 10-year Greek bond rate (the 10Y GBR); *b)* the EURO STOXX 50 volatility index, denoted as VSTOXX (V2X), which reflects the implied volatility on the European stock index and is a good proxy for market risk aversion; and *c)* Calendar Time (see Figure 2 in the Appendix).[10] Both 10-year bond rates and VSTOXX data series are extracted from Bloomberg.

Using Greek rates as a transition variable will allows us to investigate whether the dynamic of conditional correlations between Greek and our selected countries' bond rates can be explained by the progressive deterioration of the Greek macroeconomic outlook. Significant increases in correlations between Greek and selected countries' long term rates would then suggest that markets anticipate a deterioration of those countries' economic prospects on the back of the deterioration of the Greek's, while a decrease in correlation would on the contrary reflect a decoupling between markets perception our countries' economic outlook.[11]

The choice of the VSTOXX as the transition variable would allow us to gauge in 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. An increase in correlations between Greek and our selected countries' bond rates would provide evidence of contagion effects[12] from between Greece. Eventually, using calendar time as transition variable, we will implement a TVSCC-GARCH to gauge the possible decrease in conditional correlation over our two samples. A decrease in sovereign bond correlations in Europe would then be in line with the view of accrued differenciation of sovereign credit risks among European countries by markets.[13]

[10] The model taking then the form of a time-varying smooth transition conditional correlation (TVSTCC-GARCH) model which correspond to the modeling of an STCC-GARCH with Time as the transition variable (see **?**).

[11] De Santis (2012) also focuses on the impact of the deterioration of the Greek economic outlook, focusing notably on the successive downgrades of the Greek sovereign rating on the Euro area.

[12] See section 2 for the definition of financial contagion

[13] Contrasting strong level of integration on European bond markets in the early 2000's

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.[14] 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 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). 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).[15] 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

(notably highlighted by Pagano & von Thadden (2004), several points out a surge in bond markets rates differenciation following the deterioration of public finances in Europe (see notably Attinasi et al. (2012), Barbosa & Costa (2010) and Borgy et al. (2011).

[14]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.

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

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

To avoid inconsistent parameter estimates, we will first test the constancy of correlations against bivariate STCC-GARCH models (i.e 10Y GBR vs. our selected countries' bond rates) with each of our three transition variables and then directly test the constancy of correlations against bivariate DSTCC-GARCH models with first Time and the 10 GBR and then Time and the VSTOXX. 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.

With Time as transition variable, we observe a change in correlations for Ireland and Portugal in 2010, probably suggesting a further decrease in correlations of these countries' long term rates vis-à-vis Greek's as the crisis unfold. Time also allows to explain correlation changes for Ireland, Spain and Portugal in 2011, probably on the back of accrued differenciation of these countries by markets this year. TVSCC-GARCH estimates results for peripheral countries should permit to seize to which extent correlations between Greeks and other peripheral countries dropped in 2010 and 2011 (see Table 1 in the Appendix).

Using Greek bond rates as the transition variable, no changes in correlations are observed except for Spain in 2010 and for all peripheral countries in 2011 (Ireland, Portugal and Spain). Correlations for Peripheral countries' appear to particularly sensitive to 10Y GBR changes and probably decreased as country-specific credit risks become distincter for investors over the period. Markets' volatility in Europe (using the VSTOXX as transition variable) explains changes in correlations for all countries except Italy and Spain in 2010 and France and Portugal in 2011 (see Table 1 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.[16]

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

We observe a drop in correlations for 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

[16] DSTCC-GARCH estimates will be provided in the extent that Time, the 10Y GBR and/or the VSTOXX allow to explain correlation changes.

background and indebtedness level (see Table 2 and Figure 4 in the Appendix).

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.

For 2011, DSTCC-GARCH models are directly estimated for our three peripheral countries, taking into account both the Time and the 10Y GBR on the correlations changes. As expected conditional correlation between Greece and other highly indebted peripheral countries progressively decreased in 2011 as markets become aware of the divergences of fundamentals between other peripheral countries and Greece: in Spain, the parliament agreed on September 7th 2011 to enclose a Golden rule in the Spanish constitution to mitigate concerns over public finances, while Irish and Portuguese correlations dropped significantly in 2011 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. When focusing on the end of 2011, we however observe a slight rebound in correlations for Spain and Ireland as Greek rates peak to their highest period-level on the back rumors of a possible Greek exit of the Euro-area. (see Figure 5 and Table 4 in the Appendix).

3.2.3 Estimation results with the VSTOXX as 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 **??** 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.

Correlations for Ireland, Italy and Spain dropped from early August in 2011, on the back of 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 9 in the Appendix).

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 (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 and its extension the DSTCC-GARCH, 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 (through "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.

Those results are furthermore in line with recent studies on sovereign bond markets determinants during the crisis,[17] all confirming the distinction made by investors between sovereign risk in core and peripheral countries. In facts, contagion during the Greek debt crisis remained primarily limited to peripheral countries, spreading the gap between low yield countries and high yield countries in the Eurozone.

In a recent study, Kilponen et al. (2012) focus on the impact of the monetary and policy in Europe during the debt crisis and highlight the effects of stability programs implemented during the crisis: the authors identifying possible contagion effects related to the sensitivity of markets to announcements of the ECB's SMP during the crisis.[18] In the same respect, De Santis (2012) and Arezki et al. (2011) highlight the impact of markets news on the sovereign bond markets the latter also significantly contributing to surges in bond yields during the Eurozone debt crisis.

The number contagion channels have been steadily growing as the crisis

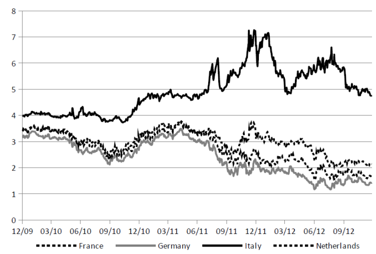
[17] See Attinasi et al. (2012) and Barbosa & Costa (2010)

[18] Kilponen et al. (2012) notably put forth the yields decrease in countries benefiting from the SMP support package and the concomitant rise Spanish and Italian Italy yields, due to the re-evaluation the riskiness of their sovereign bonds. Kilponen et al. (2012) also highlight the increase in rates observed in some countries due to ESM's decisions.

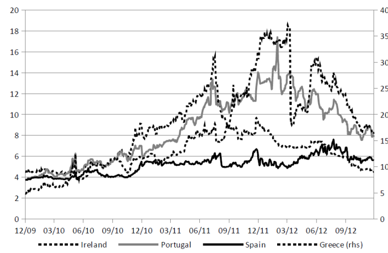
unfold. As suggest by the recent literature on the Eurozone debt crisis, news related whether to stability programs or rating agencies downgrades have deeply contributed the development of contagion phenomena during the crisis. Focusing on market news as transition variables in 2011 and 2012 would very probably provide a better understanding of bond markets interactions during the crisis.

Appendices

Figure 1: 10 Year bond rates in Euro-area countries



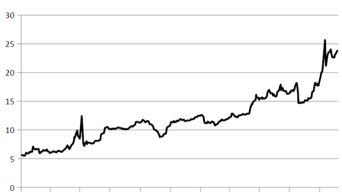
(a) Core countries



(b) Peripheral countries

Figure 2: Transition variables

(a) The 10Y Greek bond rate



(b) The VSTOXX

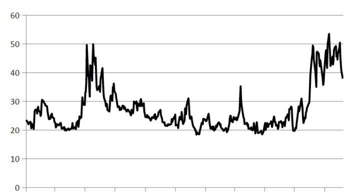
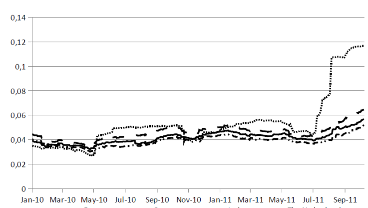
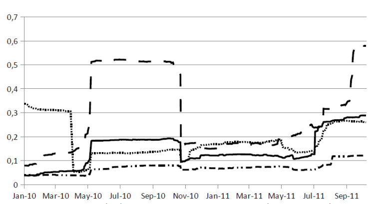


Figure 3: 10-Year bond rates volatility in the Euro-area



(a) Core countries



(b) Peripheral countries

Table 1: Results (p-values) from tests of constant correlations against TVSCC-, STCC- and DSTCC-GARCH models in 2010 and 2011.

Model	TVSCC-GARCH	STCC-GARCH		DSTCC-GARCH	
Transition variables	Time	10Y GBR	V2X	Time & 10Y GBR	Time & V2X
2010					
Core countries:					
France	0.13074	0.46194	0.02715	0.19036	0.09149
Germany	0.07259	0.32645	0.02030	0.14195	0.05484
The Netherlands	0.48290	0.97359	0.01870	0.43229	0.12417
Italy	0.15119	0.07586	0.32429	0.19032	0.01486
Peripheral countries:					
Ireland	0.041084	0.13891	0.00345	0.13763	0.01028
Portugal	0.020851	0.12971	0.04161	0.05210	0.01238
Spain	0.068273	0.03645	0.82706	0.21954	0.07177
2011					
Core countries:					
France	0.62213	0.22273	0.28926	0.26629	0.47388
Germany	0.27034	0.15880	0.00638	0.25225	0.02187
The Netherlands	0.47876	0.26128	0.01481	0.26029	0.02745
Italy	0.10905	0.20179	0.00303	0.36647	0.01734
Peripheral countries:					
Ireland	1.529e-005	1.733e-005	2.841e-007	0.00013	5.066e-006
Portugal	0.01260	0.00156	0.16569	0.01186	0.04957
Spain	0.00566	0.00443	8.971e-005	0.01264	0.00122

Table 2: Estimated correlations for bivariate TVSCC- and STCC-GARCH models in 2010

Model	TVSCC-GARCH		STCC-GARCH			
Transition variable	Time		10Y GBR		V2X	
Core countries:						
France	ρ_1	(-)	ρ_1	(-)	ρ_1	0.10441
						(0.072004)
	ρ_2	(-)	ρ_2	(-)	ρ_2	-0.07828
						(0.093024)
Germany	ρ_1	(-)	ρ_1	(-)	ρ_1	0.00467
						(0.07431)
	ρ_2	(-)	ρ_2	(-)	ρ_2	-0.32059
						(0.08565)
The Netherlands	ρ_1	(-)	ρ_1	(-)	ρ_1	0.07789
						(0.073723)
	ρ_2	(-)	ρ_2	(-)	ρ_2	-0.11851
						(0.081148)
Italy	ρ_1	(-)	ρ_1	0.61758	ρ_1	(-)
				(0.075127)		
	ρ_2	(-)	ρ_2	0.32431	ρ_2	(-)
				(0.062403)		
Peripheral countries:						
Ireland	ρ_1	0.65267	ρ_1	(-)	ρ_1	0.49125
		(0.058234)				(0.062853)
	ρ_2	0.44230	ρ_2	(-)	ρ_2	0.64295
		(0.097733)				(0.050636)
Portugal	ρ_1	0.66642	ρ_1	(-)	ρ_1	0.51121
		(0.041048)				(0.053470)
	ρ_2	0.41135	ρ_2	(-)	ρ_2	0.77656
		(0.088089)				(0.042593)
Spain	ρ_1	(-)	ρ_1	0.63589	ρ_1	(-)
				(0.061842)		
	ρ_2	(-)	ρ_2	0.37548	ρ_2	
				(0.065033)		(-)

Note: Countries without correlation estimates for ρ_1 and ρ_2 are countries for which the transition variable does not explain the regime shift between the correlation levels.

Table 3: Estimated correlations for bivariate TVSCC- and STCC-GARCH models in 2011

Model	TVSCC-GARCH		STCC-GARCH			
Transition variable	Time		10Y GBR		V2X	
Core countries:						
France	ρ_1	(-)	ρ_2	(-)	ρ_1	(-)
	ρ_2	(-)	ρ_2	(-)	ρ_2	(-)
Germany	ρ_1	(-)	ρ_2	(-)	ρ_1	-0.37984 (0.085141)
	ρ_2	(-)	ρ_2	(-)	ρ_2	-0.066452 (0.084956)
The Netherlands	ρ_1	(-)	ρ_2	(-)	ρ_1	-0.13669 (0.059541)
	ρ_2	(-)	ρ_2	(-)	ρ_2	-0.0049935 (0.060075)
Italy	ρ_1	(-)	ρ_2	(-)	ρ_1	0.41267 (0.077083)
	ρ_2	(-)	ρ_2	(-)	ρ_2	0.21295 (0.078074)
Peripheral countries:						
Ireland	ρ_1	0.92385 (0.081086)	ρ_1	0.69517 (0.060752)	ρ_1	0.56125 (0.057735)
	ρ_2	0.058668 (0.17342)	ρ_2	0.25803 (0.11379)	ρ_2	0.12600 (0.10100)
Portugal	ρ_1	0.84990 (0.039441)	ρ_1	0.78726 (0.00708)	ρ_1	(-)
	ρ_2	0.31538 (0.067427)	ρ_2	0.28361 (0.063915)	ρ_2	(-)
Spain	ρ_1	0.59733 (0.073095)	ρ_1	0.41427 (0.063869)	ρ_1	0.52525 (0.060549)
	ρ_2	0.17563 (0.10110)	ρ_2	0.16086 (0.10716)	ρ_2	0.18577 (0.090533)

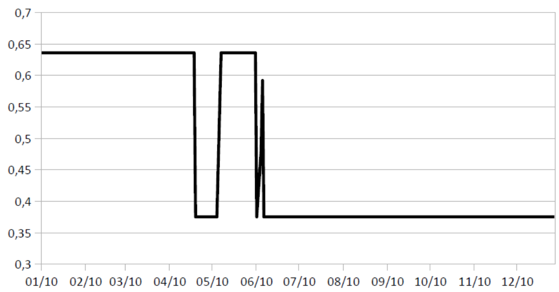
Note: Countries without correlation estimates for ρ_1 and ρ_2 are countries for which the transition variable does not explain the regime shift between the correlation levels.

Table 4: Estimated correlations for bivariate DSTCC-GARCH models in 2010

Model Transition variable	DSTCC-GARCH Time & 10Y GBR		DSTCC-GARCH Time & V2X	
2010				
Peripheral countries:				
Ireland	ρ_{11}	(-)	ρ_{11}	0.67773
				(0.071635)
	ρ_{12}	(-)	ρ_{12}	0.90000
				(0.10313)
	ρ_{21}	(-)	ρ_{21}	0.45063
				(0.062309)
	ρ_{22}	(-)	ρ_{22}	0.80860
				(0.043770)
Portugal	ρ_{11}	(-)	ρ_{11}	0.75572
				(0.80801)
	ρ_{12}	(-)	ρ_{12}	0.95883
				(0.44309)
	ρ_{21}	(-)	ρ_{21}	0.37859
				(0.26107)
	ρ_{22}	(-)	ρ_{22}	0.63492
				(0.54848)
2011				
Peripheral countries:				
Ireland	ρ_{11}	0.89113	ρ_{11}	0.81875
		(0.065494)		(0.036402)
	ρ_{12}	0.93734	ρ_{12}	-0.72905
		(0.39421)		(0.22765)
	ρ_{21}	-0.14750	ρ_{21}	0.45398
		(0.67945)		(0.076994)
	ρ_{22}	0.097033	ρ_{22}	0.12718
		(0.13667)		(0.052610)
Portugal	ρ_{11}	0.76945	ρ_{11}	(-)
		(-)		
	ρ_{12}	0.47926	ρ_{12}	(-)
		(0.12462)		
	ρ_{21}	0.90346	ρ_{21}	(-)
		(0.047805)		
	ρ_{22}	0.25429	ρ_{22}	(-)
		(0.068366)		
Spain	ρ_{11}	0.58400	ρ_{11}	0.59573
		(0.074840)		(0.069000)
	ρ_{12}	0.62550	ρ_{12}	0.66439
		(0.17947)		(0.25053)
	ρ_{21}	-0.033837	ρ_{21}	0.33418
		(0.27453		(0.21194)
	ρ_{22}	0.25587	ρ_{22}	0.17987
		(0.11823)		(0.091215)

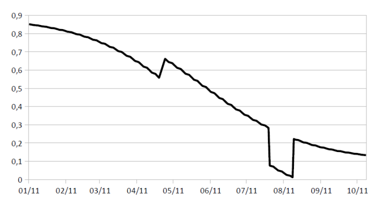
Note: Countries without correlation estimates for ρ_1 and ρ_2 are countries for which the transition variable does not explain the regime switch between correlation levels.

Figure 4: Estimates of the STCC-GARCH model with the 10Y Greek bond rate as transition variable in 2010 for Spain

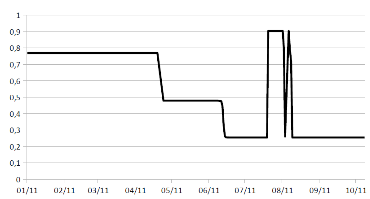


(a) Spain

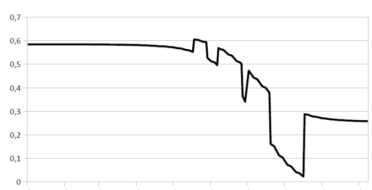
Figure 5: Estimates of the DSTCC-GARCH model with the 10Y Greek bond rate as transition variable in 2011



(a) Ireland

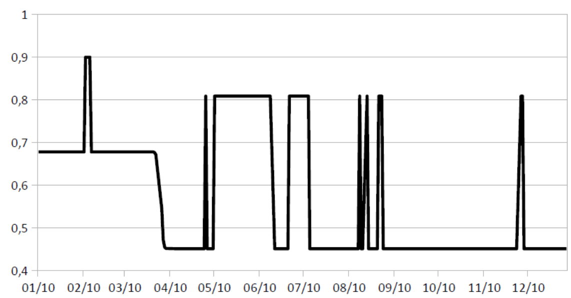


(b) Portugal

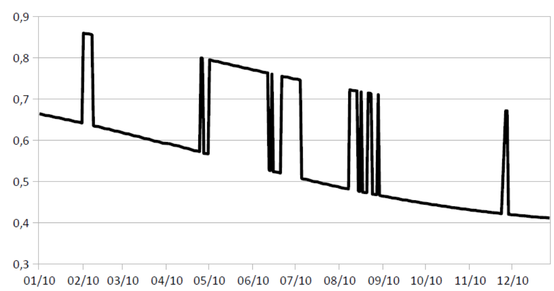


(c) Spain

Figure 6: Estimates of the DSTCC-GARCH model with the VSTOXX as transition variable in 2010

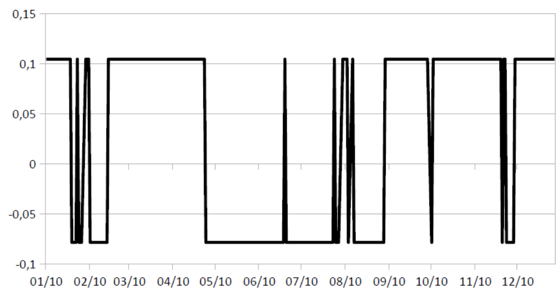


(a) Ireland

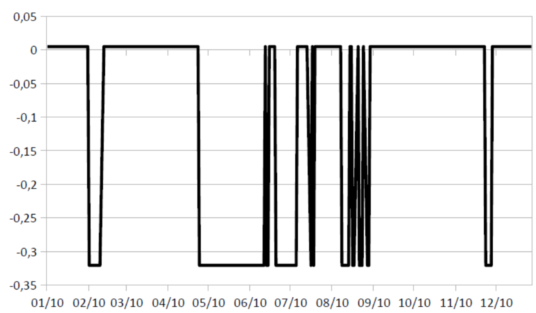


(b) Portugal

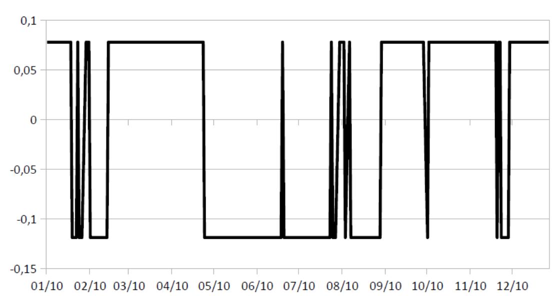
Figure 7: Estimates of the STCC-GARCH model with the VSTOXX as transition variable in 2010



(a) France

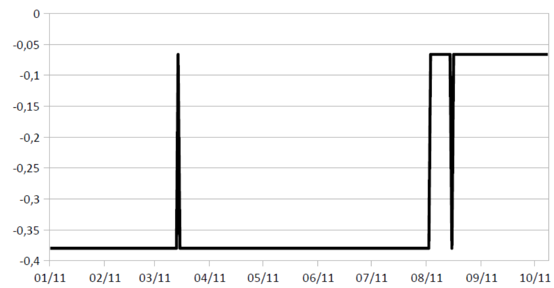


(b) Germany

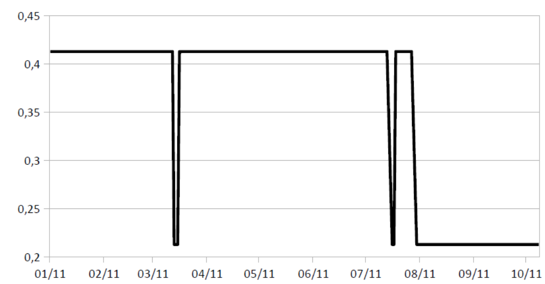


(c) The Netherlands

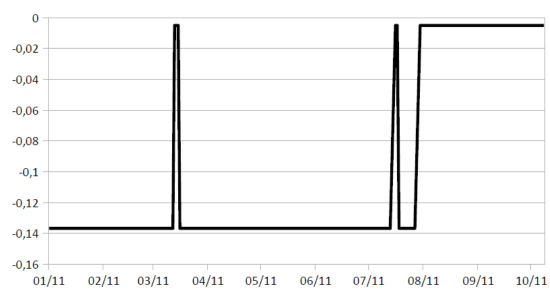
Figure 8: Estimates of the STCC-GARCH model with the VSTOXX rate as transition variable in 2011



(a) Germany

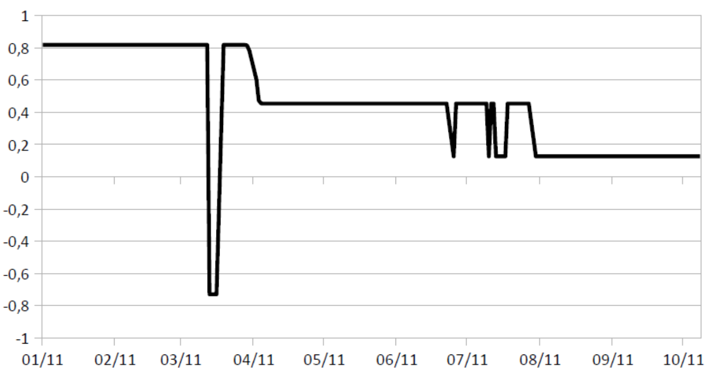


(b) Italy

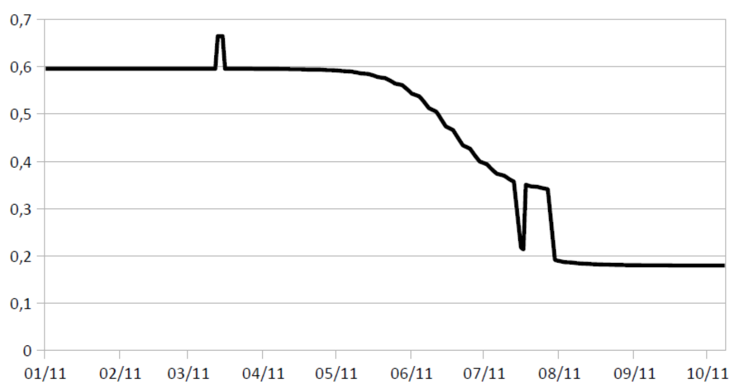


(c) The Netherlands

Figure 9: Estimates of the DSTCC-GARCH model with the VSTOXX as transition variable in 2011



(a) Ireland



(b) Spain

References

Afonso, A., Furceri, D., & Gomes, P. (2011). *Sovereign Credit Ratings and Financial Markets Linkages*. Working Paper Series 1347, ECB.

Arezki, R., Candelon, B., & Sy, A. (2011). *Sovereign Rating News and Financial Markets Spillovers: Evidence from the European Debt Crisis*. Working Paper 68, IMF.

Aslanidis, N., Osborn, D., & Sensier, M. (2008). *Co-movements between US and UK stock prices: the roles of macroeconomic information and time-varying conditional correlations*. Research Discussion Papers Series 96, Centre for Growth and Business Cycle.

Attinasi, M.-G., Checherita, C., & Nickel, C. (2012). *What explains the Surge in Euro Area Sovereign Spreads During the Financial Crisis of 2007-2009?* Working Paper Series 1131, ECB.

Barbosa, L. & Costa, S. (2010). *Determinants of Sovereign Bond Yield Spreads in the Euro Area in the Context of Economic and Financial Crisis*. Economic Bulletin 350, Banco Portugal.

Bekaert, G., Ehrmann, M., Fratzscher, M., & Mehl, A. (2006). *Global Crises and Equity Market Contagion*. Working Paper 17121, NBER.

Bertero, E. & Mayer, C. (1990). Structure and performance: Global interdependence of stock markets around the crash of october 1987. *European Economic Review*, 34, 1155–1180.

Billio, M. & Carporin, M. (2006). Multivariate markov switching dynamic conditional correlation garch representations for contagion analysis.

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

Borgy, V., Laubach, T., Mésonnier, J.-S., & Renne, J. (2011). *Fiscal Sustainability, Default Risk and Euro Area Sovereign Bond Spreads*. Working Paper 350, Banque de France.

Boyer, B., Gibson, M., & Loretan, M. (1999). *Pitfalls in Tests for Changes in Correlations*. International finance discussion paper, Board of Governors of the Federal Reserve System.

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., Pelizzon, L., Ravazzalo, F., & Rigobon, R. (2013). *Measuring Sovereign Contagion in Europe*. Working Paper 18741, NBER.

Chiang, T., Bang Nam, J., & Huimin, L. (2007). Dynamic correlation analysis of financial contagion: Evidence from asian markets. *Journal of International Money and Finance*, 26(7), 1206–1228.

Constanciô, V. (2012). Contagion and the european debt crisis. *Banque de France, Financial Stability Review*, (16), 109–121.

Corsetti, G., Pericoli, M., & Sbracia, M. (2012). *Some Contagion, Some Interdependence: More Pitfalls in Tests of Financial Contagion*. Discussion Paper 3310, CEPR.

Coudert, V. & Gex, M. (2010). Credit default swap and bond markets: which leads the other? *Banque de France Financial Stability Review*, 14.

De Santis, R. A. (2012). *The Euro Area Sovereign Debt Crisis: Safe Haven, Credit Rating Agencies and the Spread of the fever from Greece, Ireland and Portugal*. Working Paper Series 1419, ECB.

Delatte, A. L., Gex, M., & López-Villavicencio, A. (2012). Has the cds market influenced the borrowing cost of european countries during the sovereign crisis? *Journal of International Money and Finance*, 31(3).

Dungey, M., Jacobs, J., & Lestano (2005). *Synchronisation Of Financial Crises*. CAMA Working Papers 20, Australian National University, Centre for Applied Macroeconomic Analysis.

Dungey, M. & Zhumabekova, D. (2001). *Testing for contagion using correlations: some words of caution*. Pacific Basin Working Paper Series 09, Federal Reserve Bank of San Francisco.

Eichengreen, B., Rose, A., & Wyplosz, C. (1996). *Contagious Currency Crises*. Discussion Paper 1453, CEPR.

Fontana, A. & Scheicher, M. (2010). *An Analysis of Euro Area Sovereign CDS and their Relation with Government Bonds*. Working Paper Series 1271, ECB.

Forbes, K. (2012). *The Big C ; identifying and mitigating contagion*. Discussion paper, MIT-Sloan School of Management.

Forbes, K. & Rigobon, R. (2001). Contagion in latin america: Definitions, measurement, and policy implications. *Journal of LACEA Economia*.

Forbes, K. & Rigobon, R. (2002). No contagion, only interdependence: Measuring stock market comovements. *Journal of Finance*, 57(5), 2223–2261.

Hwang, Y.-S. & Min, H.-G. (2011). Dynamic correlation analysis of us financial crisis and contagion: Evidence from four oecd countries.

Kazi, I., Guesmi, K., & Kaabia, O. (2011). *Contagion Effects of Financial Crisis on OECD Stock Makets*. Discussion Paper 15, Open-Assessement E-Journal.

Kilponen, J., Laakonen, H., & Vilmunen, J. (2012). *Sovereign Risk, European Crisis Resolution Policies and Bond Yields*. Discussion Paper 22, Bank of Finland Research.

King, M., Sentana, E., & Wadhwani, S. (1994). Volatility and links between national stock markets. *Econometrica*, 62(4), 901–33.

King, M. & Wadhwani, S. (1990). Transmission of volatility between stock markets. *Review of Financial Studies*, 3(1), 5–33.

Longin, F. & Solnik, B. (1995). Is the correlation in international equity returns constant: 1960-1990? *Journal of International Money and Finance*, 14(1), 3–26.

Masson, P. (1998). *Contagion-Monsoonal Effects, Spillovers, and Jumps Between Multiple Equilibria.* Working Paper 142, IMF.

Mink, M. & de Haan, J. (2012). *Contagion during the Greek Sovereign Debt Crisis.* Working Paper 335, Netherlands Central Bank, Research Department.

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

Moser, T. (2003). Is the correlation in international equity returns constant: 1960-1990? *International Finance*, 6(2), 157–178.

Pagano, M. & von Thadden, E.-L. (2004). The european bond markets under emu. *Oxfors Review of Economic Policy*, 20(4), 531–554.

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

Pindyck, R. & Rotemberg, J. (1990). The excess co-movement of commodity prices. *Economic Journal, Royal Economic Society*, 100(403), 1173–89.

Schiller, R. (1989). *Comovements in stock prices and comovements in dividends.* Working Paper 2846, NBER.

Silvennoinen, A. & Teräsvirta, T. (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. & Teräsvirta, T. (2008). *Multivariate GARCH models.* Working Paper Series in Economics and Finance 669, Stockholm School of Economics.

Silvennoinen, A. & Teräsvirta, T. (2009). Modeling multivariate autoregressive conditional heteroskedasticity with the double smooth transition conditional correlation garch model. *Journal of Financial Econometrics*, 7(4), 373–411.

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