

Spillover in Euro Area Sovereign Bond Markets*

THOMAS CONEFREY

Irish Fiscal Advisory Council

DAVID CRONIN

Central Bank of Ireland

Abstract: This paper applies the Diebold and Yilmaz (2009, 2012) spillover methodology to euro area sovereign bond markets. Our analysis identifies different phases of interaction in those markets in recent years. We find a substantial increase in spillover between euro area sovereign bond markets coinciding with the bailout of Bear Stearns in March 2008. The phase of the euro area crisis from the first Greece bailout in May 2010 until the end of 2011 saw a reversal of the longstanding pattern whereby events in core euro area member state sovereign bond markets exercised a positive net influence on the periphery. In particular, the first Greece bailout coincided with significant positive net spillover from peripheral member states to the core countries. More recently, improved market conditions have seen the pre-2008 pattern re-established with the core having a stronger net impact on peripheral euro area sovereign bond markets. The analysis points to Greece having become relatively detached from other bond markets since its second bailout in March 2012. The spillover index and its components can be updated on an ongoing basis as new data become available and can provide useful information to policymakers and analysts alike.

I INTRODUCTION

The turmoil experienced in euro area sovereign bond markets has been one of the defining characteristics of the financial crisis that has been in train since 2007. One of the important features of this crisis is the possibility, and indeed likelihood, of developments in a national sovereign bond market having

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Email: thomas.conefrey@fiscalcouncil.ie
dave.cronin@centralbank.ie

adverse, or beneficial, effects on other sovereign markets. It is important, therefore, that policymakers, including central banks, seek to use all available information to understand better the complex interactions that are occurring in bond markets. The extent to which, for example, distress in sovereign markets is emanating from one country as opposed to a group of countries can influence the form of policy response to be undertaken. In this paper, we describe an indicator that can provide valuable information on the direction and extent of interactions in euro area sovereign bond markets. Moreover, the analysis allows us to provide an assessment of developments in the euro area sovereign bond market since the onset of EMU, with a particular focus on recent years.

A number of papers have discerned distinct phases in how euro area sovereign bond markets have interacted in recent years, although they differ somewhat in their timing of those phases and provide their own distinct characterisation of each. They tend, nevertheless, to identify factors influencing bond yields along common lines. Caceres, Guzzo, and Segoviano (2010) are of the view that the factors affecting sovereign bond spreads in the euro area of late are global risk aversion, contagion (defined as the probability of distress of a country conditional on other countries becoming distressed), and country-specific fundamentals. Their analysis indicates that early in the financial crisis heightened risk aversion was to the fore as euro area government bonds, particularly those of the core, benefited from flight-to-quality flows from other asset classes and between different sovereign markets. This prevailed up to September 2008. For the following twelve months, the crisis went through what they term a “systemic phase” as contagion effects came into play. In a number of member states (perhaps most notably, Ireland), sovereigns were providing support to financial institutions. This provoked a systemic response, which resulted in a lower probability of distress in some countries and also had favourable effects on others. In a third phase, commencing in October 2009, spreads started to diverge. This indicates, in their view, country-specific factors coming to the fore at that time.

Mody (2009) and Mody and Sandri (2012) are two related papers that have identified what they see as critical events in the euro area sovereign bond crisis focusing on how the influence of economies’ financial sectors on sovereign yields has evolved over time. The earlier paper identifies the rescue of Bear Stearns by the Federal Reserve Bank of New York in March 2008 as an event that saw sovereign bond spreads subsequently widening whenever the outlook for a domestic financial sector deteriorated. The later paper picks out the nationalisation of Anglo Irish Bank in January 2009 as a point in time when thereafter financial shocks had a greater and more immediate impact on sovereign yields. Kalbaska and Gatwoski (2012) study contagion among

European sovereigns using correlation analysis. They find that the “peripheral” member states (Greece, Ireland, Italy, Portugal, Spain), those countries under the most obvious stress, have less ability to generate contagion than core EU countries.

In this paper, we add to these assessments of the relationships between European sovereign bond markets by using a spillover index methodology (developed by Diebold and Yilmaz (DY) 2009, 2012) to measure the varying extent to which shocks in bond markets have spilled over to one another since the advent of the single currency in 1999. This approach allows one to quantify the relative importance of domestic/own market shocks and other member state/cross market shocks to a bond yield at different points in time. A higher spillover value, by indicating a stronger influence of cross market shocks on domestic bond yields, would point to extraneous events, such as, for example, distress in other markets, impacting the domestic bond market.¹ In this way, the methodology when applied to euro area sovereign bond markets can complement studies such as those cited above by showing when interaction between markets increased and decreased over time, how the direction of spillover changed as the financial crisis evolved after 2007, and whether such developments arose at important junctures in the crisis, such as at the time of the two Greece bailouts. It provides this information without having to pick out particular explanatory variables at the outset and without having to give an a priori view on which are the most important national bond markets. Similarly, the moving window application of the DY technique also avoids having to pre-specify particular break-points as can be the case with other methodologies. The application of the DY methodology here goes beyond that of some other contributions in this area by drawing out and discussing the strength and direction of relationships at the country level and between the core and peripheral country groupings in the euro area.^{2,3}

¹ The spillover index methodology produces gross spillover values, which refer to the spillover from one country to another, and net spillover values, which refer to the difference in the gross spillovers between any two countries. An appealing feature of the methodology is that one can also calculate the gross spillover from all other countries to a single country and, likewise, the net spillover value between those countries and that specific country.

² Antonakakis and Vergos (2012) and Claeys and Vasicek (2012) have applied the DY methodology to European sovereign bond markets. The former study provides a measure of the total spillover index for European bond spreads using daily data and focuses on how spillovers respond to changes in sovereign ratings. Other than for Greece, they do not show, however, the detailed spillover index components for individual member states that we provide here. The latter paper covers a relatively short sample period (2007-2012) and includes no robustness tests along the lines covered below. Furthermore, the discussion of the key, moving window results is quite limited.

³ An obvious other application of the DY methodology would be to study the interaction between the sovereign sector and the banking sector, given the importance that papers like Mody and Sandri (2012) show now attaches to that relationship in the euro area. Alter and Beyer (2013) use

The paper is organised as follows. The next section outlines the methodology and the data and assumptions underpinning the empirical analysis. Section III provides the full sample estimation results and discusses the insights that can be taken from the spillover index output. Section IV looks in detail at the results from the rolling window estimation. Section V concludes by examining some of the implications of the analysis and sovereign bond market interaction more generally for financial stability and for policy. The main finding of the study is that the movement of the total spillover index and its components over time are consistent with the view that the euro area sovereign bond crisis has changed from one driven initially by broadly-based systemic concerns to a later focus on country-specific developments. Moreover, Greece had a strong impact on other euro area bond markets around the time of its first bailout, but became relatively detached from those markets after its second bailout.

II METHODOLOGY, DATA AND ASSUMPTIONS

Standard impulse response and variance decomposition analysis relies on a method of orthogonalising the innovations in the model so that shocks can be identified. Methods such as the Cholesky decomposition are commonly used to identify VAR model shocks. The resulting impulse responses and variance decompositions, however, are dependent on the variable ordering chosen for the VAR. For example, if the bond yield spread for Ireland was the first variable in a VAR containing several bond yield spreads then a Cholesky decomposition would imply that the Ireland spread affects all of the other variables in the system in the initial period but is not itself affected by innovations in the other variables in that period. In some instances, the particular ordering imposed by the use of the Cholesky decomposition or other methods can be justified based on economic theory or well-established stylised

Footnote 3 (contd.)

a variant of the DY methodology to examine interlinkages between sovereigns and banks in the euro area between October 2009 and July 2012. The paper uses generalised impulse responses to examine the effect of shocks to CDS spreads of sovereigns and banks, and aggregates the responses into a contagion index. The results show a pattern of growing interdependences between banks and sovereigns from October 2009 up to mid-2012. This is a promising area which could be pursued in future research. Nevertheless, an examination of interaction in the sovereign bond market alone can highlight important relationships that exist there, including pre-financial-crisis relationships, and serve as a starting point for future work. Moreover, not all stress in the euro area sovereign bond market arises from the sovereign-banking link (for example, the stress that has emanated from Greece has been predominantly non-banking-based) and, thus, valuable insights can be gained by investigating sovereign bond markets on a stand alone basis.

facts. However, given the nature and complexity of interaction in sovereign bond markets, it would be preferable to calculate spillovers using a method which is invariant to variable ordering.

Koop, Pesaran and Potter (1996) developed the generalised VAR framework which produces variance decompositions which are invariant to the ordering of the variables in the VAR. Under this approach, when one variable is shocked, the effect of shocks to other variables is integrated out using the historically observed distribution of the errors. The result is a set of decompositions which are invariant to variable ordering. This more flexible methodology avoids the problem of having to specify in advance what one believes are the principal variables driving sovereign bond relationships and thus allows the data reveal the strength and direction of those relationships as they evolve over time.

Diebold and Yilmaz (2012) utilises the generalised VAR framework and organises the variance decomposition output to produce both a total spillover index and its components. Given the generalised forecast error variance decompositions for each variable in the system, the relative contribution of own variable shocks (own-variance shares) and other variables shocks (cross-variance shares) to the variance of the forecast error for each variable in the VAR are quantified and are displayed in tabular or graphical form. The spillover index provides a measure of the relative importance of the cross-variance shares, or spillovers, and thus indicates the degree of interaction between the variables.^{4,5}

The Diebold-Yilmaz approach can capture the influence of relevant non-contagion events in the euro area in recent years, such as major policy initiatives which have a cross-euro-area focus, e.g., Outright Monetary Transactions (OMT), and pan-national concerns, such as about the importance of the sovereign-banking nexus. While common shocks may impact all markets, they may have a disproportionate impact on some member states compared to others and the spillover index approach can quantify the strength and direction of such effects. It is also feasible that such common shocks can raise spillover values in general (as occurs around the time of Bear Stearns in the quantitative assessment herein). Nevertheless, given the numerous events that occurred during the sample period, in general we only focus on marked

⁴ On their approach, Diebold and Yilmaz (2012, p. 57) caution that “... although it conveys useful information, it nevertheless sidesteps the contentious issues associated with definition and existence of episodes of “contagion” or “herd behaviour”. This caveat reflects the views of Forbes and Rigobon (2002) who note that strong linkages between financial markets are not necessarily contagion and that the term “interdependence” may be a more accurate term to explain a high level of market co-movement.

⁵ The Diebold-Yilmaz methodology is outlined in Appendix II.

trends or changes in the spillover index, and that of its sub-components, and try to identify what events or factors may have caused them. We do, however, examine the behaviour of the spillover index in relation to the introduction of the Securities Market Programme and, subsequently, OMT.

We assume a “closed” euro area sovereign bond market and are in a position to examine interdependence within it since 1999. We use 10-year benchmark bond yields (sourced from Datastream) at a weekly frequency and calculate the spread for ten euro area member states (Austria, Belgium, Finland, France, the Netherlands, Portugal, Ireland, Spain, Italy, Greece) over the period 1999 to 2012. These were among the first twelve member states of the euro area, the others being Luxembourg, which is excluded here owing to its small bond market size, and Germany, whose ten-year benchmark bond yield serves in this study as the reference rate for the spread calculations for the ten member states. Spillover patterns are then estimated for the aforementioned ten countries using each country’s representative bond yield rate less the bond yield rate for Germany.⁶ The German bond yield rate is chosen as the benchmark or reference rate as is common practice in the relevant literature which focuses on European sovereign bond markets. It is the usual choice because it provides the best measure of the risk-free interest rate. Nevertheless, one shortcoming, or caveat, that follows is that this choice means that Germany cannot be examined as a separate country like other member states.

First-differences of these yield spreads are used since standard unit root tests reveal a number of the spread series to be non-stationary. The difficulty with using non-stationary series is that forecast error decomposition shares between variables often fail to settle down as the forecast horizon lengthens, thus rendering the information content of the decompositions largely void. The VAR then comprises ten variables, with each variable the first difference of a member state’s sovereign bond yield spread vis-à-vis Germany, and a constant term. The VAR lag length chosen is four, the forecast horizon is ten weeks, and a window of 200 weeks is utilised in the part of the study where rolling regressions are employed (these choices are subject to robustness tests described below).⁷

⁶ The bond yield spreads, calculated on a weekly basis, are shown in Appendix I for the period 31 December 1999 to 28 December 2012.

⁷ A lag length of four ensures that the error terms of all ten equations in the full sample estimation are serially uncorrelated. In Appendix III, the lag length is varied between one week and eight weeks in the moving window estimations and the spillover index proves not particularly sensitive to the lag length choice.

III FULL-SAMPLE ESTIMATION

The Diebold-Yilmaz method provides a measure of interdependence among asset markets by tabulating the relative contribution of own variable shocks and cross-variable shocks to the generalised forecast error variance decomposition for each variable under consideration. These individual contributions, expressed in percentage form, provide the row entries for each country in Table 1, with each row summing up to 100. Table 1 records the results from the full data sample of 31 December 1999 to 28 December 2012.

The sum of the off-diagonal entries (the cross-variance shares) in each row gives a measure of the gross-spillover-*from*-other-countries to the country in question (see column A of Table 1). The total spillover index is the average of the country entries in column A. The index then measures what proportion of the forecast error variance in the system of variables is attributable to off-diagonal elements (i.e., cross-variance shares) and provides a gauge of spillover in the system, in this case in the euro area sovereign bond market. The off-diagonal components of the column for each country add up to give its gross-spillover-*to*-all-other-countries value (the totals are shown in row B of Table 1).

The difference between each country's entry in row B and entry in column A gives a measure of net spillover between it and other countries (column C, with the entries in that column summing to zero). This indicates whether a country is a net recipient or transmitter of spillover, with the positive value for Austria, for example, in column C of Table 1 showing it to be a net transmitter for the full sample estimate.

A number of observations can be made on Table 1. First, the total spillover index has a value of 64.0 per cent so that nearly two-thirds of the forecast error variance is explained by cross-variance shares. The "Contribution from others" column (A) indicates for each individual member state the spillover to it from other member states. Greece stands out as the country with the lowest spillover from others (a value of 40.50 per cent). Likewise, it has the lowest spillover over to others (a value of 23.55 per cent in the "Contribution to others" row).

In contrast, Belgium has the highest spillover to other member states (a value of 100.16 in that row) and from others (73.37 per cent). Like the peripheral member states, Belgium is a high debt country which has had financial sector difficulties in recent times, perhaps most notably with the need to nationalise Dexia Bank Belgium in October 2011. At the same time, it is part of the historical and geographical core of the European Union. For these reasons, it is not surprising that it has relatively strong interaction with other sovereign bond markets. The off-diagonal entries in Table 1 indicate it

Table 1: Total Spillover Index and Components: Full Sample Estimation (%)

	AU	BE	FI	FR	ND	ES	IT	PT	IE	GR	A Contribution From Others	C Net Contribution
AU	30.44	16.46	9.72	14.68	8.91	5.79	7.09	1.50	3.67	1.73	69.56	8.63
BE	13.90	26.63	6.60	12.09	6.35	8.91	11.41	3.19	7.50	3.42	73.37	26.79
FI	11.59	10.76	38.41	11.00	15.39	3.36	3.95	0.51	3.92	1.10	61.59	-5.32
FR	14.35	14.64	9.66	29.45	9.04	7.09	7.90	1.47	3.64	2.76	70.55	4.89
ND	10.84	10.38	15.70	10.65	36.02	3.69	4.60	1.81	3.84	2.46	63.98	-8.41
ES	5.63	11.11	3.17	6.61	3.32	31.32	20.76	6.68	8.66	2.73	68.68	2.84
IT	6.46	13.15	3.35	7.26	3.89	19.40	27.82	6.39	9.71	2.56	72.18	10.40
PT	5.74	5.66	1.98	3.63	2.85	9.57	9.76	42.61	13.72	4.48	57.39	-19.07
IE	4.97	10.29	3.79	4.33	3.85	9.34	11.00	12.38	37.75	2.30	62.25	-3.80
GR	4.70	7.69	2.30	5.19	1.96	4.36	6.10	4.39	3.79	59.50	40.50	-16.95
B Contribution to others	78.18	100.16	56.27	75.44	55.56	71.51	82.58	38.32	58.45	23.55		640.03
Contribution including own	108.63	126.79	94.68	104.89	91.59	102.84	110.40	80.93	96.20	83.05	Total Spillover Index	64.0%

Note: for each country row, the non-diagonal entries in the body of the table represent spillovers (in percentage terms) from other countries while the diagonal (bold) entries represents that attributed to the country's own shocks. The entries in column A represent the sum of the off-diagonal entries in each row. Similarly, the entries in row B constitute the sum of the off-diagonal elements in each country column. The entries in column C represent the subtraction of the relevant country's entry in row B less its entry in column A.

having strong bidirectional interaction with Italy (a high-debt sovereign more closely associated with the core than the other peripheral member states), Spain, Austria and its neighbours, France and the Netherlands.

The strongest bilateral interaction is between Spain and Italy with Italy explaining 20.76 per cent of Spain's forecast error variance and Spain accounting for 19.40 per cent of Italy's. Turning to Ireland, it has relatively strong bi-directional relationships with Portugal, Italy, Spain and Belgium. Nevertheless, only Greece, Portugal and Finland have cross-variance spillovers that account for a lower proportion of forecast error variance, implying that its own shocks are relatively important in explaining changes in the Ireland sovereign bond yield spread.

As mentioned, the final column in Table 1 provides a measure of net spillover for each member state (calculated as the contribution to others less the contribution from others). In a situation where there are bidirectional spillover effects at play between countries, the net spillover value will indicate in which direction the greater strength of influence occurs and the extent of that influence. When a rolling window estimation procedure is undertaken, the net spillover value will indicate whether a country is more dominant in its influence on other countries at the time certain events occur. For example, one may expect Greece's influence to have grown stronger on other countries than their influence on it after the poor state of its public finances became known in late 2009. The net spillover value provides a measure of whether that is the case or not.

Belgium exerts the largest net spillover to other member states (at 26.79 per cent) followed by Italy (10.40 per cent). In contrast, both Portugal and Greece are net recipients of spillover (−19.07 per cent and −16.95 per cent, respectively). Ireland is broadly balanced between the spillover imparted to-and-from it and its gross "to others" and "from others" values are close to the average of 64.0 per cent.

IV MOVING-WINDOW ESTIMATION

While the full-sample estimation of the spillover index and its components is interesting in its own right, the DY methodology is more informative when estimated on a moving window basis as it allows one to see how spillover patterns have evolved over time. Accordingly, we estimated the spillover index on a 200-week rolling window basis and, as with the full sample estimation, a four-lag VAR and ten-week forecast horizon. The first estimate is for the 200-week sample ending 31 October 2003 and the final one has an end-date of 28

December 2012. The resultant plot of the rolling total spillover index is shown in Figure 1. Total spillover index values are reported for all but 14 windows out of 478 estimated.⁸

Figure 1: *Total Spillover Index: 200 Week Rolling Window Estimation (%)*

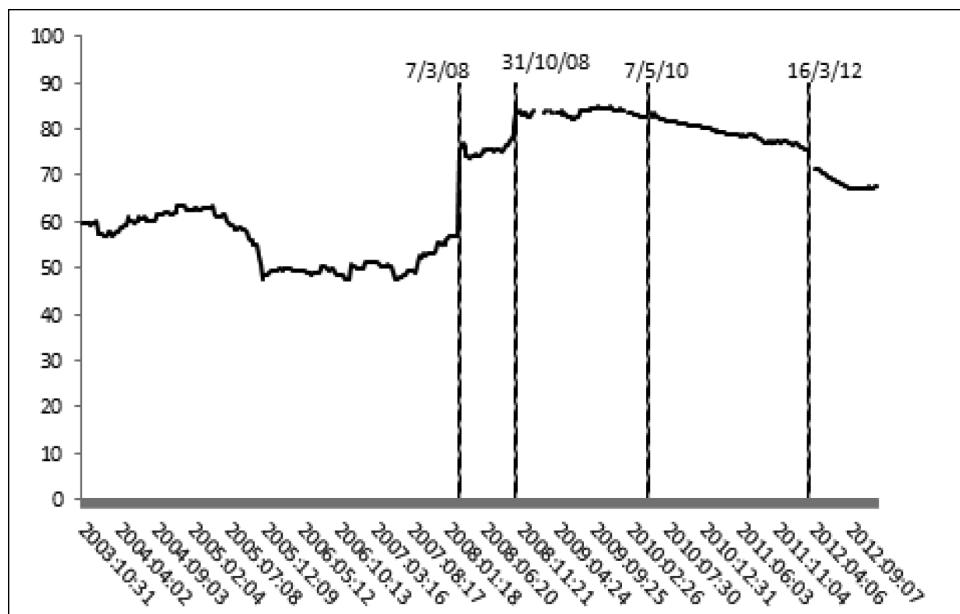


Figure 1 includes four vertical lines marking dates when distinct changes in the total spillover index and/or in its components took place in the post-2007 era (they are also included, without the specific dates, in each subsequent figure). Three of the four occur at about the time of events that would be considered important to sovereign bond market developments during the sample period. They are for the moving windows ending 7 March 2008 (Bear Stearns bailout), 7 May 2010 (the first Greece bailout), 16 March 2012 (the second Greece bailout). The fourth date (31 October 2008) coincides with the end of a one month period in which there was a number of bank bailouts in Europe starting with Ireland (in late September 2008) and ending with Sweden (late October 2008). Acharya, Drechsler and Schnabl (2011) indicate that that month saw a rise in sovereign CDS values, reflecting a shift in default risk from the banking sector to that of the sovereign.

⁸ A spillover index value will not be reported if any of the sovereign bond yield spread series has explosive roots for the period under consideration. A situation where only 3 per cent of moving window estimations have this property, as happens here, appears to be quite good in the context of other applications of the DY methodology seen by the authors.

4.1 *Robustness Tests*

Before proceeding to examine the moving window estimates in detail, we conducted a number of robustness tests to ascertain the sensitivity of the rolling total spillover index estimates to the choice of VAR lag length, forecast horizon, and size of the moving window.⁹ In panel (a) of Appendix III, we plot the median, minimum and maximum values for all sub-periods estimated by eight different lag lengths, ranging from having a VAR with a one-week lag only up to a VAR having lags of one to eight weeks, while maintaining the 200-week window and 10-week forecast horizon. While there is some disparity between the three values in the earlier years, the qualitative movements over time among the three are alike. The numerical values are of similar magnitude in later years.

In panel (b), the forecast horizon is varied between six and 14 weeks while maintaining the VAR lag length at four. There is effectively no sensitivity of the total spillover index to the forecast horizon according to the median, maximum and minimum values. This is a desirable property as it indicates convergence in forecast error decompositions as the horizon increases.

In panel (c), the total spillover index estimates using two different moving window sizes are shown. The 200-week option is that chosen for the estimation conducted in this section and which has been already shown in Figure 1. The total spillover index estimated using a 100-week window (with VAR lag length of four and forecast horizon of ten weeks) has a similar pattern to the 200-week window except for the 2007-8 period when the 100-week window index moves more gradually than the more abrupt shift for the other window option. The analysis shows that the 200-week window is much better by way of reporting spillover values in general. In the common periods of estimation (from late 2003 onwards), there are, as already noted, only 14 windows out of 460 among the 200-week estimations where spillover values are not returned by the econometric procedure owing to explosive roots. In contrast, there are 57 missing values when the window is 100 weeks and most of those occur in the later, financial crisis period, which is of greatest interest to us.

We chose to estimate the VARs with weekly data. There is no requirement to select any particular frequency of data when applying the total spillover index methodology.¹⁰ We did, however, estimate the total spillover index using

⁹ The coefficients in a VAR will be estimated imprecisely. It is good practice then to vary the lag length of the VAR, as well as the size of the estimation window, to address this estimation feature and to see whether the output of the VARs (in this case, forecast error variance decompositions) are sensitive to alternative equation specifications.

¹⁰ In their 2009 paper, Diebold and Yilmaz use weekly data in analysing nineteen global equity markets from the mid-1990s up to 2007 while in their later, 2012 paper, daily data are used in studying interaction across a number of asset class markets in the United States between 1999 and 2009.

daily data with each window comprising 200 days of observations. The index plot for the period 31 October 2003 to 28 December 2012 is shown in panel (d). While a valid representation in its own right, the daily spillover index, on our reading, does not lend itself as easily to the type of interpretation that we believe we can take from its weekly counterpart.

We estimated the total spillover index using the generalised VAR framework where decompositions are invariant to variable ordering. It is also possible to estimate using an orthogonalised forecast error variance decomposition, such as is employed by Diebold and Yilmaz (2009). We employ it here with the ordering of the countries dictated by the size of each country's GDP in 2012. Consequently, France, as the country with the largest GDP, is first in the VAR ordering and the ordering continues on a declining size-of-output basis to Ireland as the tenth country in the ordering, reflecting it having the lowest GDP. Not only is the orthogonalised alternative a robustness check on the generalised VAR approach but the ordering chosen for it may provide some insight into whether the ranking of country sizes matters for the influence of shocks, i.e., whether shocks in bigger countries may have greater cross-country impact. The two spillover indices are shown in panel (e) and one can see that the pattern of the indices is broadly similar over time, suggesting that country size is unimportant. The difference in spillover values between them is not particularly large either.

We chose to estimate the VARs without “control variables”, which would take account of financial developments occurring outside of the euro area sovereign bond market itself. As a sensitivity exercise, we did, however, conduct a sample of estimations where contemporaneous values of the first difference in the spread between the Euribor and EONIA (a measure of the interbank risk premium), the first difference of the S&P 500 index (to proxy for international stock market conditions) and the first difference of the CBOE Volatility Index (VIX) (a measure of overall market sentiment, suggested by Claeys and Vasicek (2012)) as exogenous variables. Including these variables has no material impact on the decompositions.

A final robustness check involved using the US 10-year Treasury yield as the numeraire in the calculation of bond spreads. Not only does this provide an alternative risk-free rate but it also allows a yield spread for Germany to be included as an eleventh variable in the system. The resulting rolling spillover index is quite similar to that in Figure 1 after August 2008.

4.2 *Total Spillover Index*

Returning to Figure 1, the pre-crisis period saw broadly unchanging total spillover index values from late 2005 until early 2008. Prior to that, spillover values had been declining over time. Arghyrou and Kontonikas (2012) find

bond market-pricing behaviour in EMU was governed by a “convergence-trade” model in the pre-August 2007 period according to which investors bought the bonds of peripheral member states in the hope that they would converge to those of Germany. This expectation was self-fulfilling given the purchasing of those bonds. Macroeconomic risks were either ignored or neglected (i.e., not priced). The total spillover index in Figure 1, which was close to or above 50 per cent throughout the pre-crisis period, may reflect this behaviour as bond spreads moved in a similar direction or followed one another. Subsequent to mid-2007, Arghyrou and Kontonikas argue that market-pricing became influenced more by macroeconomic fundamentals and international risk.

In Figure 1, the estimation window ending in the week of 7 March 2008 marks the largest single shift in the spillover index throughout the moving-windows estimation period. The index increases from a value of 56.75 per cent in the week ending 29 February 2008 to a value of 75.70 per cent the following week. The rescue of Bear Stearns occurred on 14 March 2008. Both Reinhart (2011) and Mody and Sandri (2012) identify that event as significant in tying financial crises to the sovereign.¹¹

The substantial increase in the spillover index in March 2008 denotes much greater interaction occurring between euro area sovereign bond markets subsequently. The underlying yield data indicate the ten euro area countries’ bond yield spread vis-à-vis Germany rising after Bear Stearns. Germany, therefore, may have been the chief beneficiary among euro area member states of a generalised flight-to-quality in the wake of Bear Stearns.¹² Nevertheless, all government bonds may have fared reasonably well on this front at that time since favourable fiscal conditions (at least on a surface reading) would have promoted sovereign bonds in general as a substitute for riskier assets. Thus, we believe there are likely two effects at work behind the marked rise in spillover values. First, the ten euro area countries’ bond yields rose relative to Germany which would have represented a common factor at play between those markets and thus generated a stronger relationship/interaction between spreads. Second, government bonds in general would have benefitted from a flight-to-quality which would also have been a common factor at work in the euro area sovereign bond market.

Caceres, Guzzo and Segoviano (2010) characterise the subsequent period from October 2008 to September 2009 as a time when government bond yields

¹¹ Mody and Sandri (2012, p. 199) argue that the rescue of Bear Stearns “... marked the start of a distinctively European banking crisis”.

¹² De Santis (2012) finds that a stronger demand for the German Bund, resulting from higher risk aversion among investors, was an important factor in the pricing of euro area spreads from September 2008 to August 2011.

at first rose together relative to swap yields and then declined. This, they argue, reflected, initially, contagion effects occurring across markets as government support for financial institutions in one member state had adverse effects on others' bond yields as well as in that country. Later, a lower probability of distress in some countries following policy intervention benefitted others. Both developments suggest greater interaction occurring between markets and it is perhaps unsurprising, therefore, that the total spillover index in Figure 1 increased to, and was maintained at, values of over 80 per cent from October 2008 onwards.

Manasse and Zavalloni (2012), as well as Caceres, Guzzo and Segoviano, find the influence of country-specific fundamentals on sovereign bond spreads becoming increasingly important during the crisis. This should have led to less interaction and a lower spillover index. Such an effect is not evident in Figure 1 until 2010 and then only seems to take effect gradually.¹³ It may be that the downgrade of Greece's sovereign bonds in April 2010 and its first bailout in the following month (indicated in Figure 1 by the vertical line at 7 May 2010) were important events in initiating the greater relative importance of idiosyncratic effects.

Subsequently, the spillover index has fallen slowly but progressively from values of about 83 per cent in May 2010 to a closing value on 28 December 2012 of 67.41 per cent. During this period, the public finances of the peripheral member states came under scrutiny, there were selected downgrades by rating institutions, and bailout programmes were initiated in a number of member states. It is nevertheless the case that, in spite of these country-specific developments, the final window index estimate of 67.41 per cent is well above the immediate pre-Bear Stearns values.

4.3 Gross-Spillover-From Values at the Country Level

In Figures 2a and 2b, the rolling estimates of the gross-spillover-from values for the core and peripheral member states, respectively, are shown. These represent the country equivalents of the total spillover index as each explains the proportion of individual country shocks explained by cross-country (off-diagonal) spillovers (i.e., they are akin to the full-sample country values in column A of Table 1).

The patterns in the country panels broadly mimic that of the overall index with spillover levels ratcheting up and remaining high after March 2008. This is especially the case for the core member states (Figure 2a). A notable feature

¹³ Manasse and Zavalloni (2012) highlight November 2009, when the 2009 Greece deficit projection was revised upward from 5 per cent to 12.7 per cent, as an important turning point in the market's perspective. Our analysis suggests that that change occurred later.

of those charts is that whereas there were clear divergences in spillover values prior to the Bear Stearns bailout among the five core member states (most notably between Finland and Belgium), they all experience high values in its wake.

Turning to the peripheral countries, they too undergo a step-up in spillover after March 2008. There are some marked differences in values across these countries from March 2012 on. In the case of Greece, there is a break at the fourth vertical line marking (16 March 2012) with a drop in gross spillover from 71 per cent to 46 per cent at that time. This end-week was one when there was a formal EU backing of a second bailout for Greece and when that country agreed a “debt swap” deal with its private sector lenders. The effect was to see its yield spread fall from 44 per cent on 9 March to 16 per cent on the following Friday. Somewhat ironically perhaps, the gross spillover values for Greece for the remainder of 2012 indicate its sovereign bond market having become largely detached from those of other euro area countries from March 2012 onwards, even though its bond yield is now closer to those of other member states than was the case prior to the second bailout.¹⁴ Portugal and Ireland also saw a clear reduction in spillover from other countries at that time, although by much less than occurred for Greece. Smaller, but still noticeable, falls in spillover occur for Italy, Finland and France.

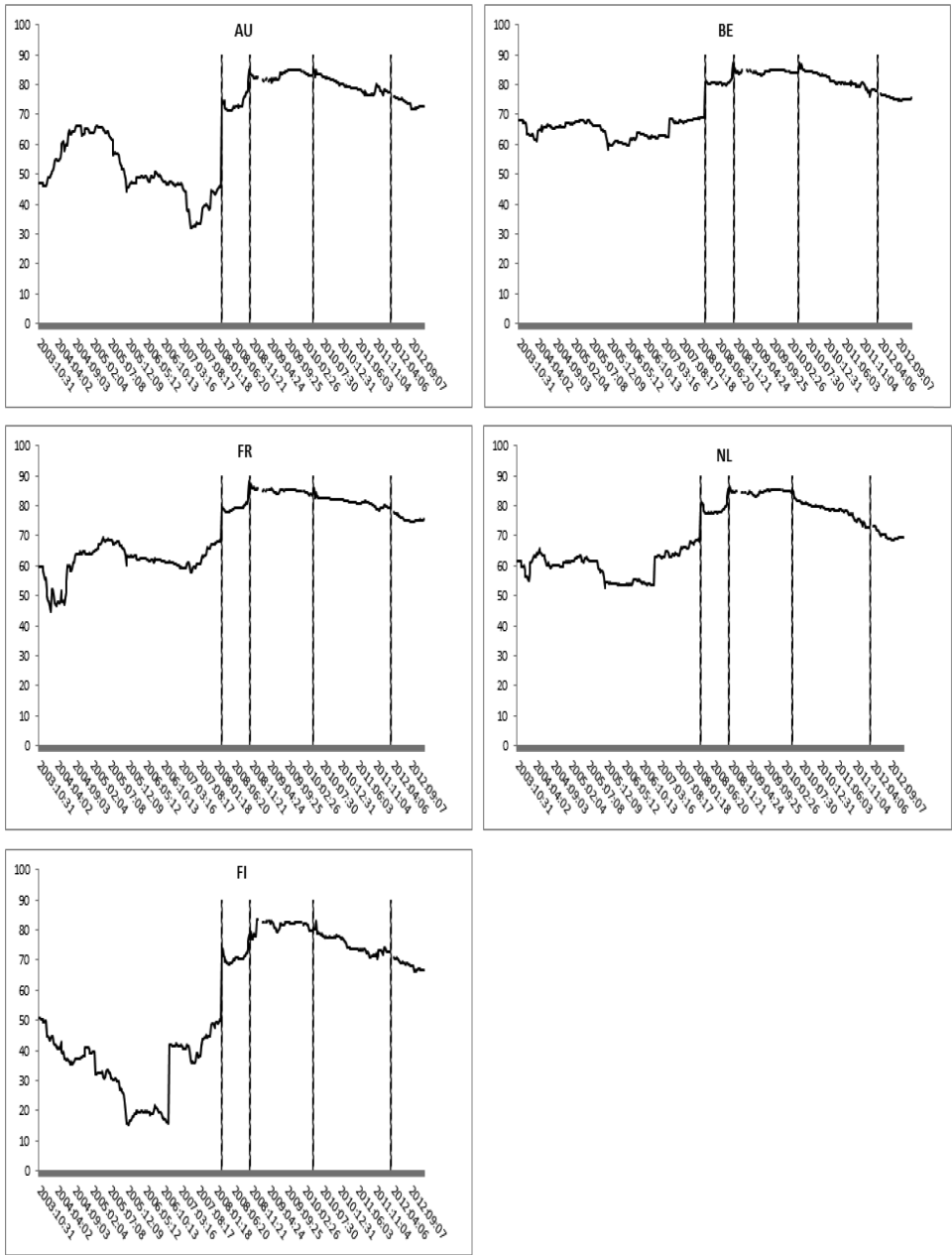
4.4 *Net Spillover Values at the Country Level*

Figures 3a and 3b contain the net spillover values for the ten euro area countries (akin to the full-sample estimates in column C of Table 1). An initial observation is that the moving window which saw the largest change in gross spillover values (that ending 7 March 2008) was one when there was little change in net spillover values. This provides support for the view that euro area sovereign bond markets were subject to common influences at that time (a generalised flight to sovereign bonds and Germany benefitting more from this compared to the other ten euro area countries).

Sudden changes in net spillover values are, however, in evidence on 31 October 2008. The upsurge in Greece’s net spillover to other countries is close to 30 per cent while Ireland’s increases by some 19 per cent. These rises are, however, temporary in nature (the Greece spread rose to a relatively large

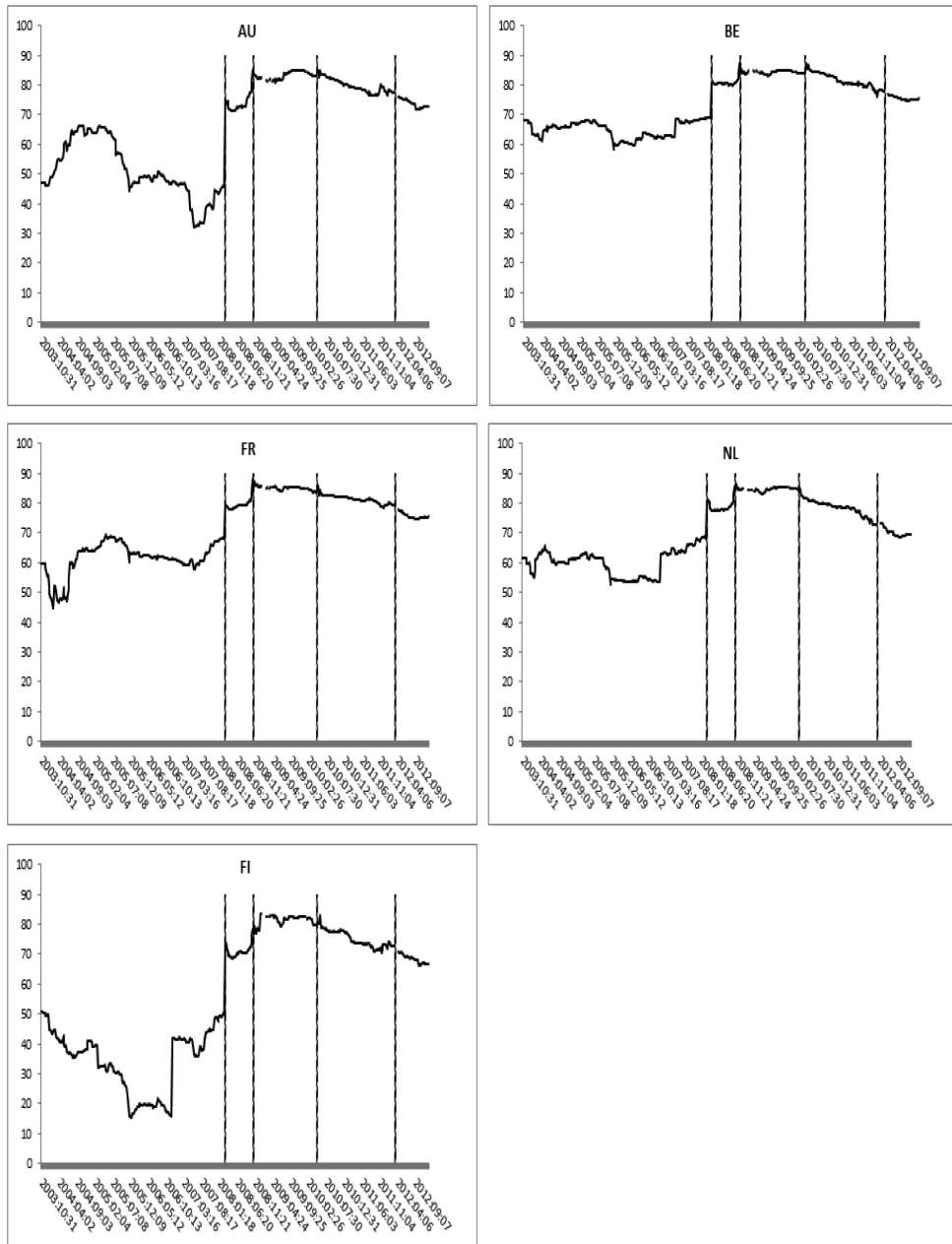
¹⁴ Employing a dynamic conditional correlation-generalised autoregressive conditional heteroskedasticity (DCC-GARCH) model of the relationship between Greece bond spreads and that of six other euro area member states, Missio and Watzka (2011) find a rise in the correlation coefficients between Greece and, in turn, Portugal, Spain, Italy and Belgium during mid-2010. These coefficients fell in value soon after. Their interpretation of this development is that this reflected bad news about Greece impacting those other bond markets but that its effect was not sustained over time. In contrast, the spillover index results presented here point to Greece decoupling from other markets much later.

Figure 2a: *Gross Spillover from Others: Core Member States (%)*



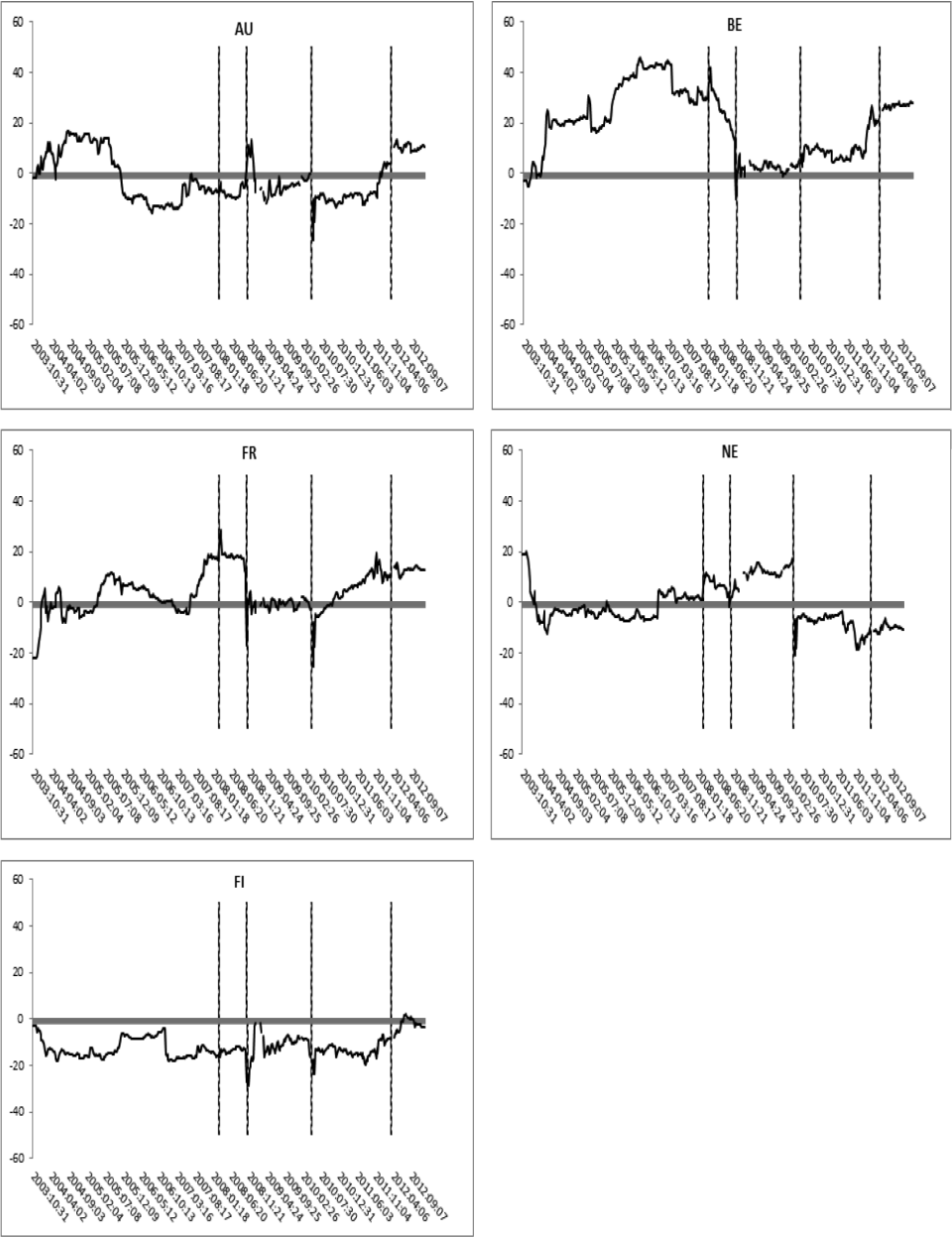
Note: Vertical lines indicate the dates marked in Figure 1.

Figure 2b: Gross Spillover from Others: Peripheral Member States (%)

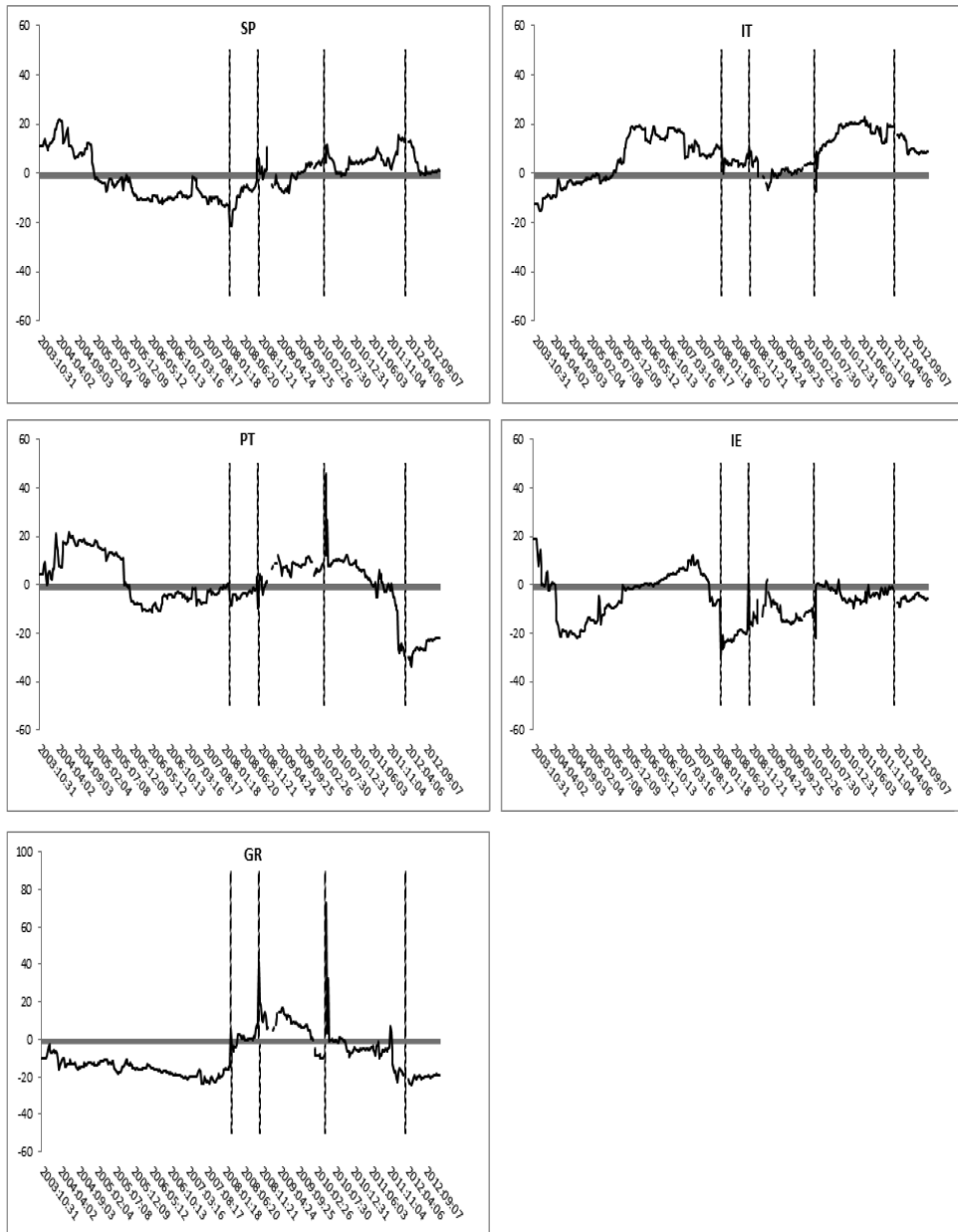


Note: Vertical lines indicate the dates marked in Figure 1.

Figure 3a: *Net Spillover: Core Member States (%)*



Note: A positive value indicates that net spillover is from the member state to all the other member states while a negative value indicates that net spillover is from all the other member states to the particular member state. Vertical lines indicate the dates marked in Figure 1.

Figure 3b: *Net Spillover: Peripheral Member States (%)*

Note: A positive value indicates that net spillover is from the member state in question to all other countries while a negative value indicates that net spillover is from all other member states to the particular member state.

Vertical lines indicate the dates marked in Figure 1.

extent that week before declining the following week) and there appears to be no particular economic/financial event in late October 2008 to shed light on these changes.

Sharp movements in net spillover values are most notable at the third highlighted date, 7 May 2010, the week of the first Greek bailout (it was agreed on 2 May). Greece's spread increased from 6.1 per cent the previous week to 9.5 per cent that week before falling subsequently. All other member states also experienced a temporary rise in their spreads at that time with Portugal the closest comparator to Greece by way of the scale of the increase. Large positive changes in net spillover occur for those two countries, while Austria, France and the Netherlands have the largest negative changes. It would not be unexpected if this event (the bailout) had generated a strong spillover effect from peripheral countries to the core countries and the econometric results back this up.

No abrupt changes in countries' net spillover indexes, however, occur on the occasion of the second Greek bailout in March 2012. Greece's yield spread over the Germany rate experienced declines in its gross spillover-to and –from other countries values at that time of over 20 per cent. This could be interpreted as Greece becoming relatively detached from the other euro area sovereign markets at the time of its second bailout. Its own shocks by end-2012 accounted for over 50 per cent of its forecast error variance decomposition, much higher than the other countries. Figure 3b indicates Greece to have become a net recipient of spillover from other countries since late-2011, as have Portugal and Ireland. Among the other peripheral countries, Spain and Italy are net transmitters of spillover in the later part of the overall sample period, as are Austria, Belgium and France.

4.5 *Core Versus Periphery*

These patterns at the individual country level suggest that further insights could be gained by displaying net spillover values over time on the basis of country groupings. If we use the core (Austria, Belgium, France, Finland, the Netherlands) and periphery (Portugal, Ireland, Italy, Greece, Spain) groupings, we obtain a net spillover pattern as shown in Figure 4.¹⁵ Before 2008, net spillover was generally from the core to the periphery. Likewise, this property held in the first phase of the crisis between March and October 2008. This suggests that events in core country sovereign bond markets exercised greater influence on peripheral country markets than in the

¹⁵ The net spillover value here is simply calculated by adding the net spillover values for the core countries. The sum of the net spillover values for the peripheral countries will have the opposite sign but same absolute value as for the core countries in each rolling sample.

opposite direction. This might be unsurprising if country-specific issues were not as yet important, as has been posited by commentators discussing the early stages of the financial crisis.

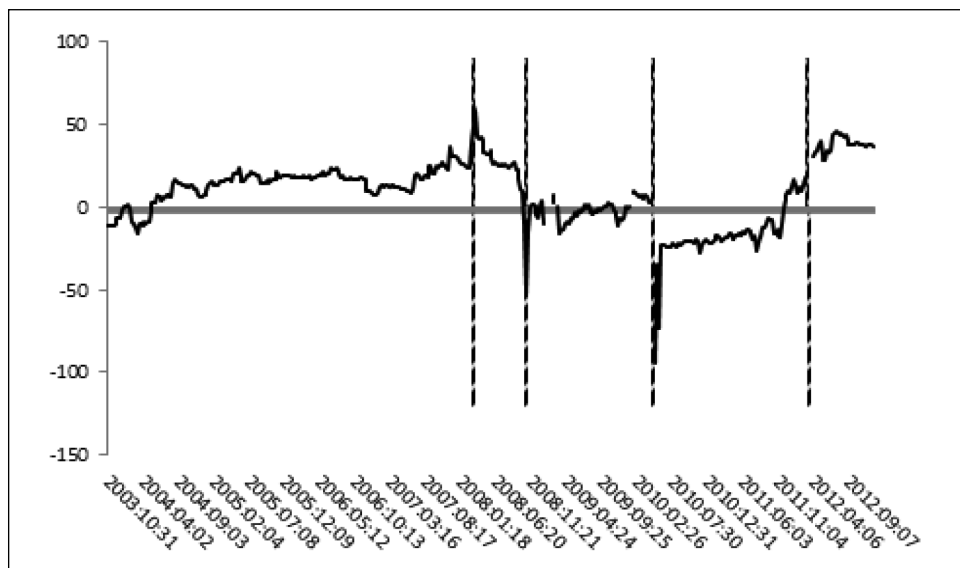
By early May 2010, Greece's specific sovereign debt problems were more obvious. The bailout programme agreed at that time coincides with the sharp decline in net spillover in Figure 4 to a value of -94.03 per cent. This is largely attributable to a positive spike in Greece's net spillover value but also to a jump in Portugal's (see the relevant panels in Figure 3b). The net spillover values in Figure 4 remain negative until December 2011 so that the periphery appears to be the dominant influence on sovereign market developments during that time. This may not be unexpected given financial market concerns about debt sustainability in the periphery and its potential consequences for the core.¹⁶ Since late 2011, however, the core has regained the stronger net influence in euro area sovereign bond markets. Given that the total spillover index has declined since 2010, one could ask whether the state of affairs before 2008 with regard to influence and interaction is being reconstituted in euro area sovereign markets. The passing of time and, with it, new data may provide a more clear-cut view but there appears to be some movement in that direction in the data available.

4.6 *A Closer Look at the Two Greece Bailouts*

In Tables 2a and 2b, respectively, we provide measures of *changes* in the spillover index between 30 April 2010 and 21 May 2010 and between 9 March 2012 and 13 April 2012. During these two intervals, the first and second Greece bailouts took place. Most likely reflecting turbulent behaviour of euro area sovereign bond markets around these bailouts and the introduction of the Securities Markets Programme in mid-May 2010, there are no spillover index values reported for the intervening weeks around the bailouts (7 May 2010 and 14 May 2010 for the first bailout; 16 March 2012, 23 March 2012, 30 March 2012, 6 April 2012 for the second bailout).

The changes in the spillover index's components from 30 April 2010 to 21 May 2010 (Table 2a) are quite different to that from 9 March 2012 to 13 April 2012 (Table 2b). On both occasions, there is little change in the total spillover index value (it rises by 1.3 per cent at the time of the first bailout and falls by 4.2 per cent when the second bailout occurs). Focusing on the components of the spillover index at the time of the first bailout, it can be seen that all gross "contribution from others" entries (column A of Table 2a) rise in value except

¹⁶ De Grauwe and Ji (2012, 2013) are of the view that spreads behaviour in the peripheral member states during 2010-11 was disconnected from debt dynamics or measures of fiscal space and was the result of negative market sentiments. This behaviour would also contribute to, or explain, the high spillover values during that time.

Figure 4: *Net Spillover: Core to Periphery (%)*

Note: A positive value indicates that net spillover is from the core to the periphery while a negative value indicates that net spillover is from the periphery to the core.

Vertical lines indicate the dates marked in Figure 1.

for Greece which falls by 7.14 per cent and Portugal which declines by 4.90 per cent. These two member states' gross spillovers to other member states are much higher after the first Greek bailout (up 74.29 per cent and 31.98 per cent, respectively – see row B of Table 2a), while those of Austria, France and the Netherlands are much lower. Its column in Table 2a indicates that the rise in Greece's spillover to other member states is greater for the other peripheral member states and Belgium than for the other core member states.¹⁷ The net spillover charts already discussed indicate this sizeable cross-over effect from Greece in the wake of its first bailout to be short lived.

When the second bailout took place (Table 2b), the changes in net spillover values (column C) are quite small. The most noticeable numbers in that table are the decline in Greece's "contribution from others" (–23.87 per cent in column A) and "contribution to others" (–26.71 per cent in column C) values. These lower spillover values have been maintained since the second bailout and point to Greece's relative decoupling from the other main euro area member states' sovereign bond markets. The declines in its gross contribution

¹⁷ Beetsma, Giuiliodori, de Jong and Widiyanto (2013) find that since September 2009 bad news in one of the peripheral countries tends to have larger effect on other peripheral countries than on non-peripheral member states.

from/to values at the time of the second bailout mainly accrue from its bilateral relationships with the other peripheral member states.¹⁸

4.7 Securities Markets Programme (SMP) and Outright Monetary Transactions (OMT)

To address malfunctioning in securities markets and to help the monetary policy transmission mechanism to operate normally, the ECB announced a number of non-standard interventions during the financial crisis. The SMP was initiated in May 2010 and allowed the ECB and other central banks to intervene directly in public and private debt markets. Following the speech by ECB president Mario Draghi in London in July 2012, the technical details of Outright Monetary Transactions in sovereign bond markets were announced in September 2012 and the SMP was terminated.¹⁹ The OMT allows for unlimited outright purchases of sovereign bonds in secondary markets, particularly those with a maturity of between one and three years.

As both the SMP and OMT announcements were two of the key non-standard policy measures implemented by the ECB in response to the euro area sovereign debt crisis, we examine whether there is evidence of significant changes in the spillover index around the time of both announcements. To the extent that both announcements resulted in an easing of financial market tensions and reduced contagion effects, this should be reflected in a decline in the overall spillover index.

The announcement and implementation of the SMP appears to have coincided with a modest reduction in spillovers in the months immediately after May 2010. In late May 2010, the spillover index stood at 83.6 per cent, close to its record high of 84.7 per cent recorded in October 2009. Between end-May and end-July, the index declined by over 2 per cent. The fall in the level of the index continued until the end of the year at a slow rate so that by December 2010 it was just over 3 per cent lower than its late May value.

Turning to the OMT announcement, as shown in Figure 1, the overall spillover index was on a generally declining trend from early 2012. Between the first week of January 2012 and the week preceding Draghi's London speech, the spillover index declined by about 8 per cent. Although the index continued to fall thereafter, the overall decline between the announcement of OMT in July and the final week of December 2012 measured less than 1 per cent. Overall then, there is no evidence of a sharp step-change in the spillover index coinciding with either the SMP or OMT announcements.

¹⁸ A full set of charts showing gross to and from rolling spillover values for each country is available from the authors on request.

¹⁹ <http://www.ecb.int/press/key/date/2012/html/sp120726.en.html>

Table 2a: *Change in Total Spillover Index and Components: First Greece Bailout (%)*

	AU	BE	FI	FR	ND	ES	IT	PT	IE	GR	A		C	
											Contribution		Net	
											From Others		Contribution	
AU	-1.59	0.43	-0.23	-0.38	-0.91	0.53	0.43	-0.06	1.41	0.37	1.59		-26.70	
BE	-2.59	-3.39	-2.00	-4.17	-5.60	0.75	-1.32	5.57	0.65	12.10	3.39		-3.12	
FI	0.07	0.12	-0.50	0.39	-0.29	0.42	0.78	-0.64	0.43	-0.78	0.50		-7.40	
FR	-0.87	-0.18	-0.33	-2.26	-1.61	0.48	-0.94	0.97	0.24	4.51	2.26		-22.59	
ND	0.44	0.22	0.49	0.27	-0.06	-0.61	-0.17	-1.36	0.89	-0.11	0.06		-37.70	
ES	-3.22	-0.91	-0.06	-3.45	-6.34	-4.08	-1.87	5.87	-1.12	15.17	4.08		-1.60	
IT	-2.36	-0.66	-0.72	-2.43	-4.19	0.65	-3.06	4.07	-1.30	10.01	3.06		-10.91	
PT	-5.74	-0.41	-1.35	-4.46	-6.90	-0.02	-2.07	4.90	-0.59	16.64	-4.90		36.88	
IE	-4.00	-0.13	-0.67	-3.21	-5.86	-0.52	-1.06	8.83	-9.76	16.39	9.76		-8.30	
GR	-6.84	1.78	-2.04	-2.91	-5.93	0.81	-1.62	8.73	0.87	7.14	-7.14		81.43	
B Contribution to others	-25.11	0.27	-6.89	-20.3	-37.64	2.48	-7.84	31.98	1.46	74.29	12.66			
Contribution including own	-26.70	-3.12	-7.40	-22.6	-37.70	-1.60	-10.91	36.88	-8.30	81.43				
											Total Spillover Index		1.27%	

Table 2b: Change in Total Spillover Index and Components: Second Greece Bailout (%)

	AU	BE	FI	FR	ND	ES	IT	PT	IE	GR	A Contribution From Others	C Net Contribution
AU	1.57	1.18	0.06	1.30	-0.16	0.41	-0.69	-0.15	-1.05	-2.47	-1.57	6.84
BE	1.27	1.11	0.28	0.76	-0.09	0.13	-0.53	-0.10	-0.20	-2.64	-1.11	4.29
FI	0.63	0.83	2.25	0.23	0.93	-0.19	-1.17	-0.48	0.25	-3.28	-2.25	0.11
FR	1.67	0.78	0.55	1.30	0.06	0.10	-1.23	-0.21	-1.14	-1.88	-1.30	2.51
ND	0.37	0.69	0.21	-0.08	-0.51	-0.59	-0.84	-0.24	-0.34	1.32	0.51	-1.07
ES	0.67	0.41	-0.09	0.20	-0.04	1.31	0.60	0.54	-0.41	-3.21	-1.31	0.28
IT	-0.03	0.17	-0.69	-0.37	0.02	1.31	2.42	0.92	0.18	-3.94	-2.42	-3.80
PT	0.81	-0.80	-0.66	0.84	0.08	1.05	1.10	3.88	-0.59	-5.71	-3.88	-0.53
IE	-0.79	0.45	0.35	-1.07	0.44	-0.02	0.44	0.59	4.52	-4.90	-4.52	-5.78
GR	0.66	-0.54	-2.17	-0.61	-1.81	-3.22	-3.89	-5.28	-7.01	23.87	-23.87	-2.84
B Contribution to others	5.27	3.18	-2.15	1.21	-0.57	-1.03	-6.22	-4.41	-10.3	-26.71	-41.74	
Contribution including own	6.84	4.29	0.11	2.51	-1.07	0.28	-3.80	-0.53	-5.8	-2.84	Total Spillover Index	4.17%

V CONCLUSION

The econometric results reported in this paper have a number of salient features:

- (i) Our interpretation of the movement of the total spillover index and its components over time is that it lends support to the view that the euro area sovereign bond crisis has moved from being driven initially by broadly-based systemic concerns to a later focus on country-specific developments;
- (ii) While Greece had a strong influence on euro area bond markets around the time of its first bailout, this had diminished by the time of its second bailout. After that event, it has become relatively detached from other markets;
- (iii) There is evidence pointing to the re-establishment of spillover patterns that existed before the crisis with gross spillovers having fallen over time from 2009-10 levels and net spillover again occurring from the core to the periphery.

There are a number of important policy implications which stem from this analysis. The results suggest that the influence of peripheral member states, in particular, Greece, on the euro area sovereign bond market has diminished, at least for the moment, and that pre-crisis interaction patterns appear to be re-occurring after a period of extreme stress. This may reflect a greater focus by financial markets on market fundamentals. Systematic mispricing of sovereign risk, which can occur when fiscal and macroeconomic fundamentals are ignored, can exacerbate macroeconomic cycles (De Grauwe and Ji, 2012). An emphasis on the fundamentals of each member state can help distinguish each from one another and thus help avoid financial contagion (i.e., behaviour unrelated to fundamentals) occurring. Giordano, Pericoli and Tommasino (2013) find greater attention being paid by investors during the crisis to the macroeconomic and fiscal conditions in member states (what they call “wake-up call” contagion).²⁰ If correct, this affords member states, such as Ireland, an opportunity to distinguish their prospects from others by demonstrating positive features of their economies and/or implementing economic programmes that reassure investors as to the country’s long-term fiscal sustainability and competitiveness. Another implication of the results is that Greece becoming detached from other sovereign bond markets after its second

²⁰ De Grauwe and Ji (2013) also find evidence of investors suddenly becoming conscious of high government debt and reacting by raising bond spreads.

bailout, as the spillover index methodology indicates occurred at that time, also provides a lesson to policymakers that a credible adjustment programme can have a near-immediate effect of mitigating the influence of a distressed sovereign on other member states as well as having benefits for the particular member state.

To conclude, the spillover index methodology can provide useful information to policymakers and other market observers and analysts. Its changing value over time can be quickly updated given the immediate availability of end-of-day bond yield data. It thus could prove an informative indicator for those tasked with monitoring sovereign market developments and their implications for financial stability. We can think of a number of extensions to the current study. First, it is possible to plot bidirectional spillovers (off-diagonal elements) between pairs of countries on a rolling basis, for example, between Ireland and the other nine euro area member states under consideration. This may shine further light on the changing relationships between different sovereign bond markets at a country-to-country level. Second, measures of intra-week volatility in bond markets could be substituted for the yield spread data so that volatility spillover could be assessed. Third, it would be possible to use the spillover index methodology to investigate how the financial crisis has impacted on the interaction between different classes of financial assets in the euro area.²¹ Likewise, the methodology would seem to have promise as a basis for examining interaction between the banking sector and the sovereign.

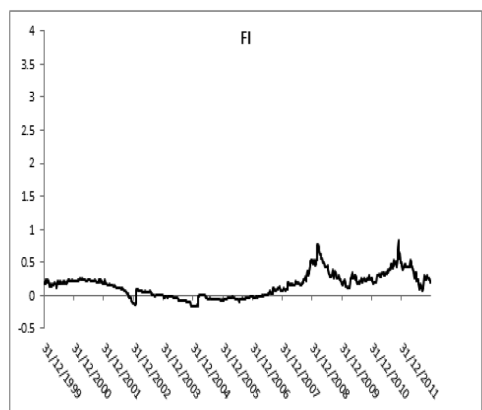
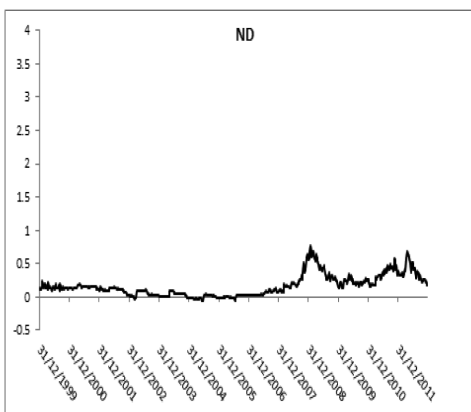
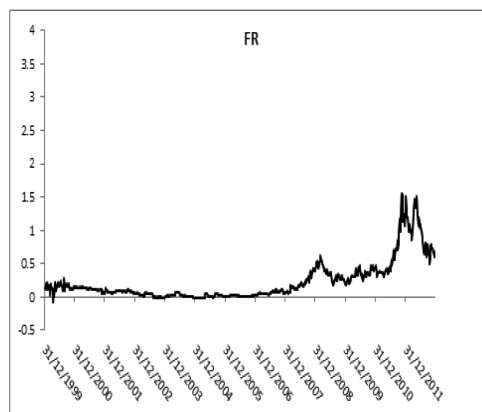
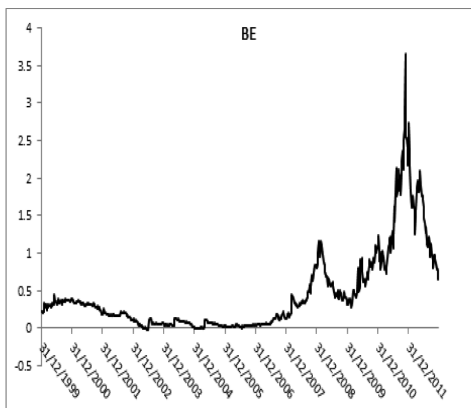
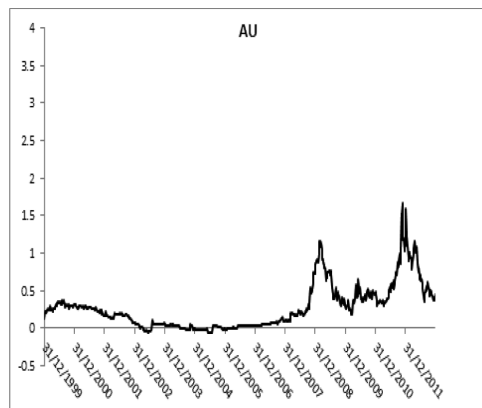
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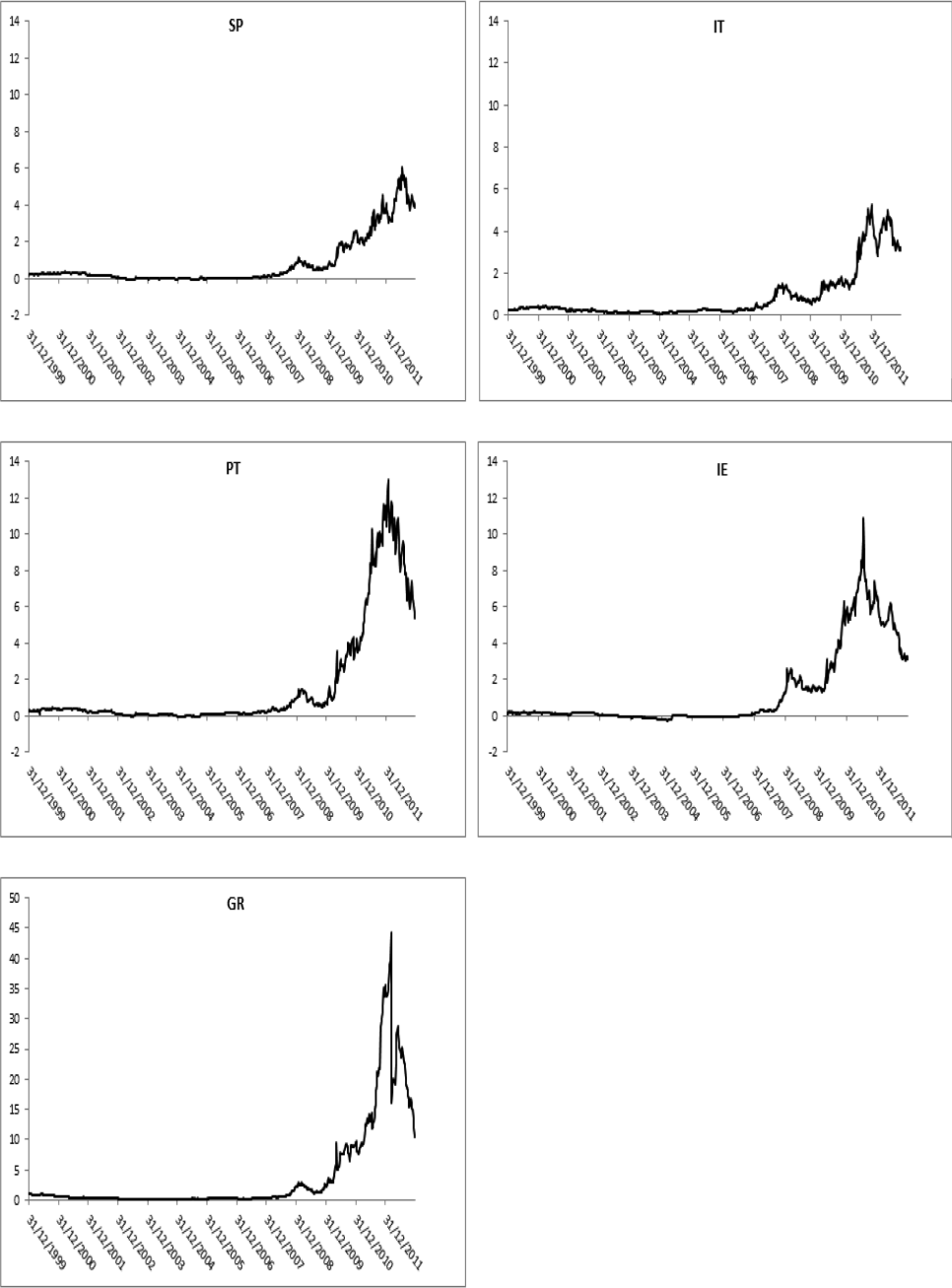
²¹ Mody and Sandri (2012) argue that not only do negative financial events now impact on sovereign bond yields but sovereign weakness can also be transmitted to the financial sector.

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APPENDIX I

Euro Area Sovereign Bond Yield Spreads (%)

Euro Area Sovereign Bond Yield Spreads (%)



APPENDIX II

Diebold-Yilmaz Methodology

Construction of the Diebold and Yilmaz spillover index relies on forecast error variance decompositions. These show the proportion of the movement in a variable's development over time due to its own shocks and that due to shocks in other variables in the vector autoregression by quantifying how much of the total variance forecast is attributed to each.

Diebold and Yilmaz (2012) use the generalised VAR framework of Koop, Pesaran and Potter (1996) and Pesaran and Shin (1998) which produces generalised variance decompositions. In this form of VAR, variance decompositions are invariant to the ordering of the variables in it. In the remainder of this appendix, we outline in summary form the VAR framework and construction of the spillover index.

The N -variable VAR(p) specification is given by

$$x_t = \sum_{i=1}^p \phi_i x_{t-i} + \varepsilon_t \quad (1)$$

Where x is a vector of variables and $\varepsilon \sim (0, \Sigma)$ is a vector of independently and identically distributed disturbances.

Assuming covariance stationarity, this specification can be rewritten in moving average form as:

$$x_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i} \quad (2)$$

Where the $N \times N$ coefficient matrices A_i observe the recursion $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \dots + \Phi_p A_{i-p}$, with A_0 an $N \times N$ identity matrix and $A_i = 0$ for $i < 0$. Variance decompositions allow the fraction of the H -step-ahead error variance in forecasting x_i owing to shocks to x_j , $\forall j \neq i$, for each i to be measured.

Cross-variance spillovers are the fractions of the H -step-ahead error variance in forecasting x_i owing to shocks to x_j , for $i, j = 1, 2, \dots, N$, such that $i \neq j$, while own variance spillovers are the fractions of the H -step-ahead error variance in forecasting x_i owing to shocks to x_i , for $i = 1, 2, \dots, N$. With the H -step-ahead forecast error variance decompositions denoted as $\theta_{ij}^g(H)$ for $H = 1, 2, \dots$, we get

$$\theta_{ij}^g(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h \Sigma e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h' e_i)} \quad (3)$$

Where Σ is the variance matrix for the error vector ε , σ_{ii} is the standard deviation of the error term for the i th equation and e_i is the selection vector with one as the i th element and zeros otherwise.

Each entry of the variance decomposition matrix is normalised by the sum of the elements of each row of the variance decomposition table as:

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^N \theta_{ij}^g(H)} \quad (4)$$

By construction, $\sum_{j=1}^N \tilde{\theta}_{ij}^g(H) = 1$ and $\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H) = N$.

The total spillover index is then defined as:

$$S^g(H) = \frac{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)}{\sum_{i,j=1}^N \tilde{\theta}_{ij}^g(H)} \cdot 100 \quad (5)$$

The directional spillover from all other variables j to variable i is measured as:

$$S_{.i}^g(H) = \frac{\sum_{j=1, j \neq i}^N \tilde{\theta}_{ij}^g(H)}{\sum_{j=1}^N \tilde{\theta}_{ij}^g(H)} \cdot 100 \quad (6)$$

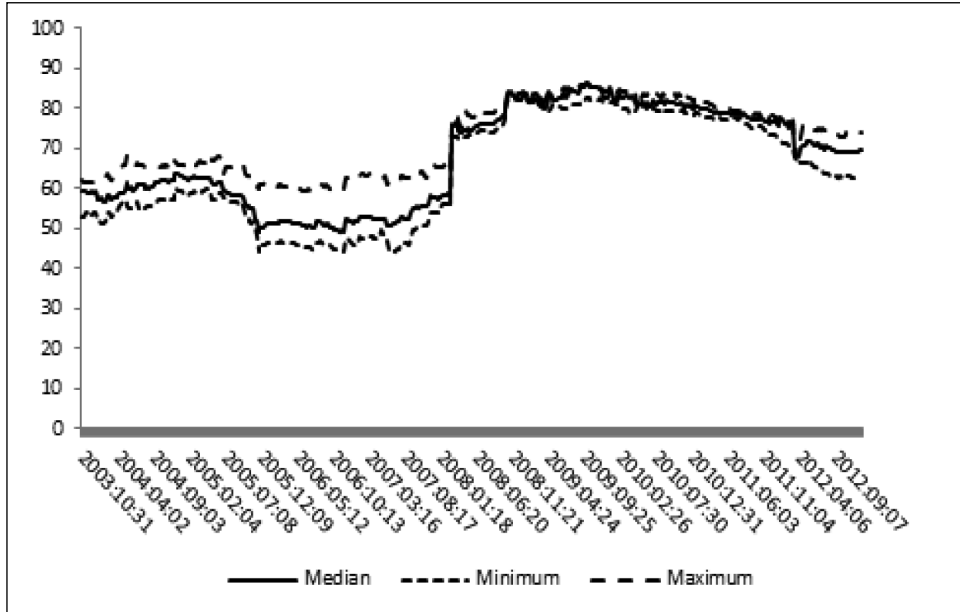
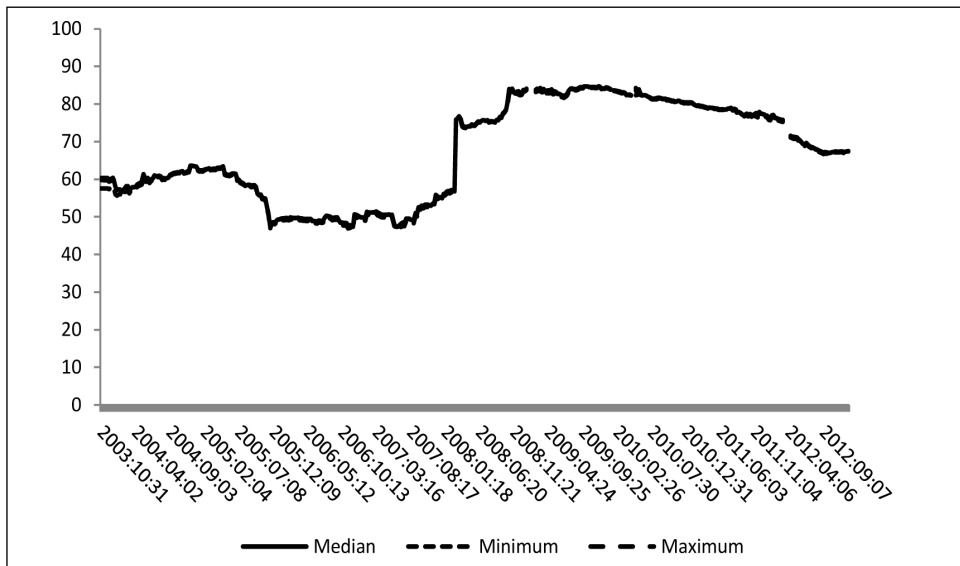
Likewise, the directional spillover from market i to all other markets j is calculated as:

$$S_{.i}^g(H) = \frac{\sum_{j=1, j \neq i}^N \tilde{\theta}_{ji}^g(H)}{\sum_{j=1}^N \tilde{\theta}_{ji}^g(H)} \cdot 100 \quad (7)$$

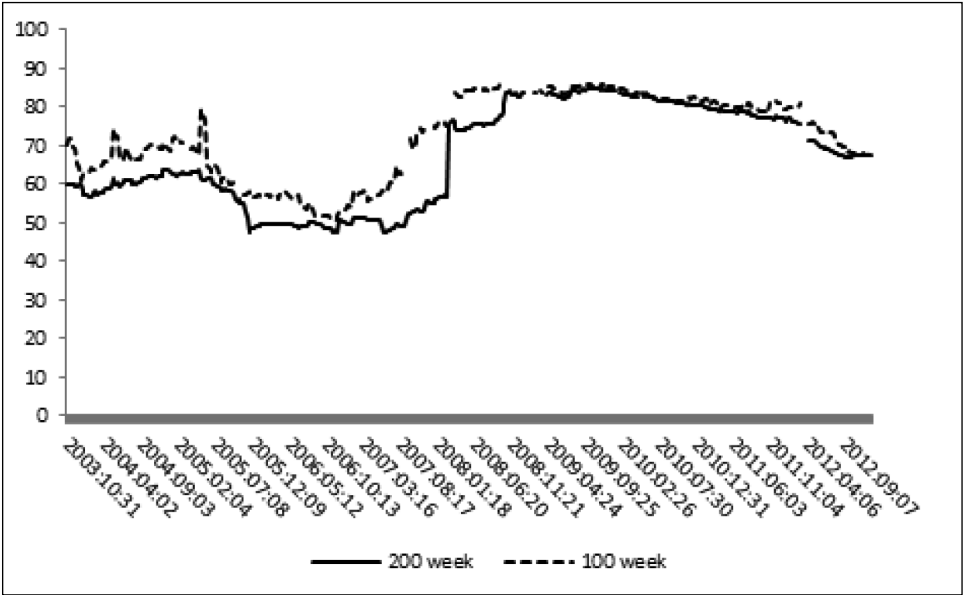
The net volatility spillovers from market i to all markets j can be calculated as the difference between gross volatility shocks transmitted to and gross volatility shocks received from all other markets:

$$S_i^g(H) = S_{.i}^g(H) - S_{.i}^g(H) \quad (8)$$

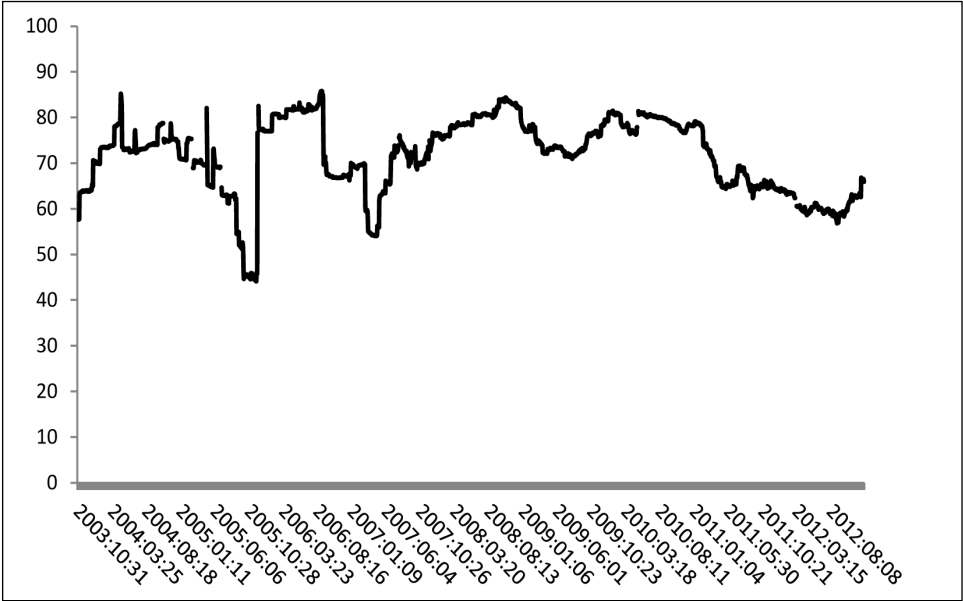
APPENDIX III

*Robustness Tests (%)**(a) VAR Lag Lengths: One to Eight Weeks**(b) Forecast Horizon: Six to Fourteen Weeks*

(c) Rolling Window: 100 Week Versus 200 Week



(d) Rolling Window: Daily Data



(e) Rolling Window: Generalised Ordering versus Orthogonalised Ordering