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"Causality and contagion in peripheral EMU public debt markets: a dynamic approach"

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Abstract

Our research aims to analyze the causal relationships in the behavior of public debt issued by peripheral member countries of the European Economic and Monetary Union (EMU), with special emphasis on the recent episodes of crisis triggered in the eurozone sovereign debt markets since 2009. With this goal in mind, we make use of a database of daily frequency of yields on 10-year government bonds issued by five EMU countries (Greece, Ireland, Italy, Portugal and Spain), covering the entire history of the EMU from its inception on 1 January 1999 until 31 December 2010. In the first step, we explore the pair-wise causal relationship between yields, both for the whole sample and for changing subsamples of the data, in order to capture the possible time-varying causal relationship. This approach allows us to detect episodes of contagion between yields on bonds issued by different countries. In the second step, we study the determinants of these contagion episodes, analyzing the role played by different factors, paying special attention to instruments that capture the total national debt (domestic and foreign) in each country.

JEL classification: E44, F36, G15
Keywords**:** Sovereign bond yields, causality, time-varying contagion, euro area, peripheral EMU countries.

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1. Introduction

After the stability that characterized the first 10 years of the European Economic and Monetary Union (EMU), the serious tensions that arose in international financial markets in August 2007 due to the US subprime crisis, and the collapse of the financial institution Lehman Brothers in September 2008, sparked a global financial crisis that affected the real sector and caused a rapid, synchronized deterioration in most major economies. The economic and financial crisis highlighted the imbalances within the euro area which had probably been undervalued during the previous years of stability. It was as if the sovereign debt markets had underestimated the possibility that governments might default.

From August 2007 onwards, yield spreads of euro area issues with respect to Germany spiraled in parallel with the rise in global financial instability that led to the "flight-to-quality", resulting in a transfer of funds towards assets with a lower risk (the German bund) and an increase of the risk premium in the other EMU countries (see Figure 1). Therefore, in only four years the EMU bond markets went from a situation of stability and tranquility to their current situation of turmoil.

With the rescues of Greece and Ireland in 2010 and of Portugal and Greece again in 2011, it seems increasingly clear that the origin of the sovereign debt crisis in Europe goes beyond the imbalances in public finances. The interconnection between the private and public debt is obvious. In fact, while the ratio of public debt in the euro area dropped from 66% in 2003 to 63% in 2007, household debt increased from 41% to 56% of GDP during the same period and financial institutions increased their debt levels from 126% of GDP to close to 200%[2].

Indeed, the main causes of the debt crises in Europe vary according to country. In Ireland, the crisis was mainly due to the private sector, particularly a domestic housing boom which was financed by foreign borrowers who did not require a risk premium related to the probability of default (see Lane, 2011). In Spain, since absorption exceeded production, the external debt grew and the real exchange rate appreciated, implying a loss of competitiveness for the economy. Unlike previous expansions, the resort to financing was not led by the public sector but by private households and firms. The average value of the debt-to-GDP ratio during the period 2007-2010 in Spain surpassed 80% in the public sector and was close to 90% in the private.

[2] As we explain in Sub-section 3.2, private debt data have been compiled using the Monetary Financial Institutions (MFI) balance sheet statistics provided for each country by the European Central Bank (see Table 6).

In contrast to Ireland and Spain, the origin of the debt crisis in Greece and Portugal was the structural deficit in the government sector. If the crisis finally spreads to Italy, this structural deficit would be the possible cause. Greece and Italy's large fiscal deficit and huge public debt are the cumulative result of chronic macroeconomic imbalances[3]. However, the case of Portugal illustrates the importance of foreign debt. Portugal's debt-to-GDP ratio (63% at the end of December 2010) was much lower than Belgium's (123%), but whilst the latter is a net creditor towards the rest of the world, the markets are worried about Portuguese high external debt[4] (specifically, that of its private sector: banks and enterprises).

Some studies have found a strong relationship between risk premium and a wide range of vulnerability indicators that cover not only the fiscal position, but also (1) the current account balance and the net position towards the rest of the world, (2) the reliance on external funding to finance a domestic expansion, (3) the appreciation of the real exchange rate and the loss of competitiveness and (4) the cross-border banking system linkages to the government sector, among other things.

The IMF (2010) and Barrios *et al.* (2009) present empirical evidence of the strong relationship between current account deficits and foreign debt and the behavior of sovereign risk premium. Moreover, Gros (2011) contends that foreign debt is more important than public debt, and that this may have a number of implications for the ongoing eurozone crisis[5].

Other authors (Bolton and Jeanne (2011), Allen *et al*. (2011)), have focused on the study of cross-border banking system linkages to the government sector. Cross-border banking brings important stability benefits, but it also brings costs. Its effect on risk diversification is a key benefit. Since the assets of cross-border banks will be less exposed to country-specific shocks, they are less likely to have to constrain their lending or to fail to honor their debts. Therefore, the presence of foreign banks in a country is likely to enhance the stability and efficiency of the economy.

On the side of costs, foreign capital is likely to be more mobile than domestic capital. In a crisis situation, foreign banks may simply decide to "cut and run". In addition, the increase in cross-border banking activity will also tend to increase the complexity, interconnectedness, and size of

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[3] As pointed out in Gómez-Puig (2006 and 2008), in the past, Italy may have benefited from the fact that "size matters for liquidity" and thus for the success of a sovereign debt market since at the end of 2010 its market was the biggest in the euro area.

[4] The current account deficit over GDP was 9.86% in December 2010.

[5] This author points out that the importance of external debt is due to the fact that euro area governments retain full sovereignty over the taxation of their citizens, but they are bound by existing treaties and international norms and do not have a free hand in taxing non-citizens. Therefore, euro countries can always service their domestic debt, even without access to the printing press, but not their external debt.

the institutions. Since cross-border banks are more likely to be systemically relevant, their failure may impose significantly higher costs for economies than the failure of a purely domestic bank.

Another important destabilizing force is contagion: just as cross-border banking insulates the domestic economy from domestic shocks; it also exposes it to foreign ones. Moreover, since there are several channels linking the banking sector and the sovereign debt market, financial or sovereign crisis in a country can quickly spill over to other countries through an integrated banking system. All in all, the stability benefits from cross-border banking may outweigh the costs, provided its volume is not excessive.

The European Union and, especially the euro area, witnessed a significant increase in cross-border financial activity over the 10 years before the global crisis (see Barnes, Lane and Radziwill, 2010). Both the elimination of currency risk and regulatory convergence[6] can explain the important increase in cross-border financial activity in the EMU (see Kalemli-Ozcan, Papaioannou and Peydró-Alcalde, 2009). Spiegel (2009a) shows that the relative increase in bilateral bank claims involving euro area members can be attributed to three different channels: (a) a “borrower” effect, by which euro membership increases creditworthiness, (b) a “creditor” effect, which increases the attractiveness of a member country’s banks as financial intermediaries, and (c) a “pair-wise” effect such that joint membership of the euro increases the quality of intermediation when both lender and borrower are in the monetary union.

Spiegel (2009a) not only finds evidence that the pair-wise effect is the dominant one, but also that it is strongest for those country pairs that also have high levels of bilateral trade. Moreover, Spiegel (2009b) shows that the effect of the euro has been even stronger for some of the peripheral EMU countries. In particular, the sources of external financing for Portuguese and Greek banks radically shifted on joining the euro; traditionally reliant on dollar debt, these banks were subsequently able to raise funds from their counterparts elsewhere in the EMU.

In this scenario of increased cross-border financial activity in the euro area, Gray *et al*. (2008) points out the importance of identifying the channels of contagion between the banking and the sovereign sectors, not only within a country but across countries as well. On the one hand, a systemic banking crisis can induce a contraction of the entire economy, weakening public finances and thus transferring the distress to the government. This contagion effect is amplified when the financial sector has state guarantees. As a feedback effect, risk is further transmitted to

[6] The introduction of the Single Banking License in 1989 through the Second Banking Directive was a decisive step towards a unified European financial market, which subsequently led to a convergence in financial legislation and regulation across member countries.

holders of sovereign debt. On the other hand, macroeconomic imbalances in a specific country lead to rising sovereign spreads and a devaluation of the government debt that is mirrored in banks' balance sheets. In addition, sovereign or financial crisis in a country can quickly spill over to other countries through an integrated banking system.

The recent literature on sovereign debt has generally ignored these linkages. But, as the recent European sovereign debt crisis has highlighted, contagion of the crisis in one country to others through the banking system can be a major issue. Only a handful of recent papers have addressed the interaction between sovereign default and the stability of the domestic financial system. The analyses by Gennaioli, Martin and Rossi (2010), Broner, Martin and Ventura (2010), Mody (2009) and Ejsing and Lemke (2009) are among them[7].

The papers most closely related to our analysis are the studies by Bolton and Jeanne (2011), Andenmatten and Brill (2011) and Sosvilla-Rivero and Morales-Zumaquero (2011). Bolton and Jeanne (2011) analyze contagious sovereign debt crises in financially integrated economies. Under financial integration, banks optimally diversify their holdings of sovereign debt in an effort to minimize costs with respect to an individual country's sovereign debt default and to guarantee their access to public liquidity (in return for lending to private banks, central banks generally require collateral in the form of government and other highly rated securities)[8]. The central issue in their paper is the international contagion caused by the banks' exposure to the sovereign risk of foreign countries. Using data from the 2010 European stress test, they show that financial integration without fiscal integration results in an inefficient equilibrium supply of government debt[9].

Andenmatten and Brill (2011) perform a bivariate test for contagion that is based on an approach proposed by Forbes and Rigobon (2002) to examine whether the co-movement of sovereign CDS premium increased significantly after the beginning of the Greek debt crisis in October 2009.

[7] Beakert *et al*. (2011) analyze the transmission of crises to country-industry equity portfolios in 55 countries, using the 2007-2009 financial crisis as a laboratory.

[8] This latter reason may have played a particularly important role in the euro area and may explain why there has been substantially faster financial integration among euro member countries than elsewhere, as De Santis and Gerard (2006) have highlighted.

[9] The same conclusion is reached by Gros and Mayer (2011) who say that "The EU resembles a group of highly interdependent companies with large cross-holdings of equity stakes. However, the formal structure of the group is very light. There is no central authority that can give orders to individual members of the group". They conclude that the euro area can no longer avoid a stark choice: "either it sticks to the limited liability character of EMU (but in this case sovereign default becomes likely), or it moves towards a fiscal union with a mutual guarantee for the public debt of all member countries".

Unlike Forbes and Rigobon, they conclude that in European countries "both contagion and interdependence" occurred.

In the first stage of their study, Sosvilla-Rivero and Morales-Zumaquero (2011) examine the behavior of daily yields for 11 EMU countries during the 2001-2010 period, decomposing volatility into permanent and transitory components. In the second stage, they test for correlation and causality, detecting the existence of two different groups of countries – closely-linked, core EMU countries and peripheral EMU countries – whose existence is validated using a cluster analysis.

However, an important constraint in the above-mentioned empirical evidence is the fact that it ignores the dynamic component of the degree of contagion of the public debt markets. In this regard, Abad, Chuliá and Gómez-Puig (2010 and 2011) examine the European government bond market integration from a dynamic perspective, applying an asset pricing model to a dataset spanning the years 2004 to 2009. Their results suggest that, from the beginning of the financial market tensions in August 2007, markets moved towards higher segmentation, and the differentiation of country risk factors increased substantially across countries[10]. Nonetheless, the evolution of the time-varying degree of causality and contagion between different EMU public debt markets has not yet been analyzed in sufficient depth by the literature. This paper aims to carry out an analysis of this kind.

Thus, the main objectives of this paper are: (1) to test for the existence of possible causal relationships between the evolution of the yield of peripheral EMU countries' issues, (2) to examine the time-varying nature of these causal relationships and to detect episodes of contagion between them, and (3) to analyze the determinants of these contagion events considering not only macroeconomic imbalances and banking linkages, but also indicators of investor sentiment. This paper also makes three main contributions to the existing literature. First, it presents a dynamic approach to the analysis of the evolution of the degree of causality and contagion between different EMU public debt markets. Second, it makes use of a unique dataset on private debt-to-GDP by sector (households, banks and non-financial corporations) in each EMU country, built up by the authors using the Monetary Financial Institutions (MFI) balance sheet statistics provided for each euro country by the European Central Bank. Besides, cross-border banking linkages are measured using the consolidated claims on an immediate borrower basis of Bank for International Settlements reporting banks in the public, the banking and the non-financial private

[10] Although the levels were very low, the persistence of positive yield spreads against Germany detected before the beginning of the crisis (see Gómez-Puig, 2009a and 2009b) was still a reflection of incomplete integration in EMU bond markets.

sectors, as a proportion of GDP. Third, it focuses the analysis on peripheral EMU countries (Greece, Ireland, Italy, Portugal and Spain), since these are the countries which have come under fire in the markets since 2009, reflecting investors' perceptions of risks, and which to a large extent have been the cause of the current sovereign debt crisis in the whole eurozone.

The most important results of the analysis can be summarized as follows. Firstly, they provide empirical evidence of the existence of sub-periods of Granger causality in all pair-wise relationships. Given the absence of consensus about the definition of contagion, we identify contagion episodes as sub-periods of significant increase in causality. So, the results suggest that these episodes are concentrated around the first year of the EMU in 1999, the introduction of euro coins and banknotes in 2002, and the global financial crisis in the late-2000s. Moreover, they also indicate that the causality relationships between peripheral EMU yields have significantly risen during the recent crises in sovereign debt markets from 2009, providing evidence of an increase in the contagion between them.

Secondly, the results of the probit models estimated to analyze the determinants of the contagion episodes show that in all cases the variable that captures cross-border banking linkages is statistically significant. This finding suggests that, in a scenario of increased international financial activity in the euro area, contagion of the crisis in one country to other countries through the banking system can be a major issue. Nevertheless, the instruments we have used to capture macroeconomic imbalances in the different countries also indicate that these imbalances are key determinants of the probability of occurrence of a contagion episode. Lastly, regarding the role of private debt, we find evidence supporting its importance in the cases of Spain and Italy and we detect a relevant effect of foreign bank claims on banking and non-financial private sector debt-to-GDP on the probability of contagion from Ireland.

The rest of the paper is organized as follows. Section 2 presents the causality analysis and our approach for the detection of contagion episodes. In Section 3 we carry out the exploration of the determinants of these contagion events. Finally, Section 4 summarizes the findings and offers some concluding remarks.

2. Causality and contagion

2. 1. Econometric methodology

Granger's causality test is widely used to test for the relationship between two variables. However, causality tests are sensitive to lag length and, therefore, it is important that the lengths selected should be the right ones; otherwise, the model estimates will be inconsistent and misleading inferences may be drawn (see, Thornton and Batten, 1985). In this paper, we use Hsiao's (1981) generalization of the Granger notion of causality. Hsiao proposed a sequential method to test for causality, which combines Akaike's final predictive error (FPE, from now on) and the definition of Granger causality. Essentially, the FPE criterion trades off bias that arises from under-parameterization of a model against a loss in efficiency resulting from over-parameterization of the model.

Consider the following models,

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \varepsilon_t \qquad (1)$$

$$X_t = \alpha_0 + \sum_{i=1}^{m} \delta_i X_{t-i} + \sum_{j=1}^{n} \gamma_j Y_{t-j} + \varepsilon_t \qquad (2)$$

where X_t and Y_t are stationary variables [i.e., they are I(0) variables]. The following steps are used to apply Hsiao's procedure for testing causality:

i) Treat X_t as a one-dimensional autoregressive process (1), and compute its FPE with the order of lags m varying from 1 to m[11]. Choose the order which yields the smallest FPE, say m, and denote the corresponding FPE as $FPE_X(m, 0)$.

ii) Treat X_t as a controlled variable with m number of lags, and treat Y_t as a manipulated variable as in (2). Compute again the FPE of (2) by varying the order of lags of Y_t from

[11] $FPE_X(m,0)$ is computed using the formula: $FPE_X(m,0) = \frac{T+m+1}{T-m-1} \cdot \frac{SSR}{T}$, where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (1)

1 to *n*, and determine the order which gives the smallest FPE, say *n*, and denote the corresponding FPE as FPE_X (m,n)[12].

iii) Compare FPE_X (m, 0) with FPE_X (m,n) [i.e., compare the smallest FPE in step (i) with the smallest FPE in step (ii)]. If FPE_X (m,0) > FPE_X (m,n), then Y_t is said to cause X_t. If FPE_X (m,0) < FPE_X (m,n), then X_t is an independent process.

iv) Repeat steps i) to iii) for the Y_t variable, treating X_t as the manipulated variable.

When X_t and Y_t are not stationary variables, but are first-difference stationary [i.e., they are I(1) variables] and cointegrated (see Dolado *et* al., 1990), it is possible to investigate the causal relationships from ΔX_t to ΔY_t and from ΔY_t to ΔX_t, using the following error correction models:

$$\Delta X_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \varepsilon_t \tag{3}$$

$$\Delta X_t = \alpha_0 + \beta Z_{t-1} + \sum_{i=1}^{m} \delta_i \Delta X_{t-i} + \sum_{j=1}^{n} \gamma_j \Delta Y_{t-j} + \varepsilon_t \tag{4}$$

where Z_t is the OLS residual of the cointegrating regression ($X_t = \mu + \lambda Y_t$), known as the error-correction term. Note that, if X_t and Y_t are I (1) variables, but they are not cointegrated, then β in (3) and (4) is assumed to be equal to zero.

In both cases [i.e., X_t and Y_t are I(1) variables, and they are or are not cointegrated], we can use Hsiao's sequential procedure substituting X_t with ΔX_t and Y_t with ΔY_t in steps i) to iv), as well as substituting expressions (1) and (2) with equations (3) and (4).

2. 2. Data

We use daily data of 10-year bond yields from 1 January 1999 to 31 December 2010 collected from Thomson Reuters Datastream for EMU peripheral countries: Greece, Ireland, Italy, Portugal and Spain.

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[12] FPE_X(m,n) is computed using the formula: $FPE_X(m,n) = \frac{T+m+n+1}{T-m-n-1} \cdot \frac{SSR}{T}$, where T is the total number of observations and SSR is the sum of squared residuals of OLS regression (2)

Figures 1a and 1b plot the daily 10-year sovereign bond yield and the spread against the bund for each country in our sample. A simple look at these figures indicates the differences in the yield behavior before and after the financial crisis of 2008.

[Insert Figures 1a and 1b here]

Specifically, after the introduction of the euro in January 1999 and until the subprime crisis in global financial markets in August 2007, spreads on bonds of eurozone members moved in a narrow range with only slight differentiation across countries. In fact, the stability and convergence of spreads was considered a hallmark of successful financial integration inside the euro area. Nevertheless, after the subprime crisis in 2007 severe tensions emerged in financial markets worldwide, including the EMU bond market. Following the collapse of the US financial institution Lehman Brothers on 15 September 2008, the financial turmoil turned into a global financial crisis which began to spread to the real sector.

At the same time, the financial crisis showed that imbalances within euro countries still persisted, since interest rate differentials between government bond issues of participating countries, which had reached levels close to zero between 2003 and 2007 (the average value of the 10-year yield spread against the German bund moved between -4 and 20 basis points, in the case of Ireland and Greece, respectively), now reemerged. In fact, the risk premium on EMU government bonds, which had followed a secular downward trend in the past, increased strongly in 2008, reflecting investor perceptions of upcoming risks; by the end of December 2010 it reached levels of 952 basis points in Greece, 580 in Ireland, 380 in Portugal, 255 in Spain and 182 in Italy.

[Insert Table 1 here]

Table 1 presents descriptive statistics for the levels and differences of the 10-year government's yield in the above-mentioned EMU countries during the sample period (1999-2010). As can be seen, the mean is not significantly different from zero for the first differences. Normality is tested with the Jarque-Bera test (which is distributed as $\chi^2(2)$ under the null) and strongly rejected for both the levels and first differences. Since rejection could be due to either excess of kurtosis or skewness, we report these statistics separately in Table 1. Given that the kurtosis of the normal distribution is 3, our results suggest that the distribution of the yields of Greece and Ireland, as well as all the first differences, are peaked relative to the normal, while the distribution of the yields in the cases of Italy, Portugal and Spain are flat relative to the normal. Finally, regarding the asymmetry of the distribution of the series around their mean, we find positive skewness for all the variables in levels and for the first difference in the case of Italy, suggesting that their distributions have long right tails, while in the cases of the first differences of yields for Greece, Ireland, Portugal and Spain there is evidence of negative skewness and therefore distributions with long left tails.

2.3. Preliminary results

As a first step, we tested for the order of integration of the 10-year bond yields by means of the Augmented Dickey-Fuller (ADF) tests. The results, shown in Table 2, decisively reject the null hypothesis of nonstationarity, suggesting that both variables can be treated as first-difference stationary.

[Insert Table 2 here]

Following Carrion-i-Silvestre *et al.* (2001)'s suggestion, we confirm this result using the Kwiatkowski *et al.* (1992) tests (KPSS), where the null is a stationary process against the alternative of a unit root. As can be seen in Table 3, the results fail to reject the null hypothesis of stationarity in first differences, but strongly reject it in levels.

[Insert Table 3 here]

As a second step, we tested for cointegration between each of the 10 pair combinations[13] of peripheral EMU yields using Johansen (1991, 1995)'s approach. An important decision in this approach is whether to include deterministic terms in the cointegrating VAR. Deterministic terms, such as the intercept, linear trend, and indicator variables, play a crucial role in both data behavior and limiting distributions of estimators and tests in integrated processes. Results in Banerjee *et al.* (1993), Johansen (1994) and Nielsen and Rahbek (2000) show the statistical properties of the commonly used test, indicating that in some cases its size cannot be controlled, and in others there is substantial power loss. Depending on their presence or absence, the system may manifest drift, linear trends in cointegration vectors, or even quadratic trends. In practical work,

[13] Recall that the number of possible pairs between our sample of five peripheral EMU yields is given by the following formula $\frac{n!}{r!(n-r)!}=\frac{5!}{2!(5-2)!}=10.$

there seem to be only two relevant model representations for the analysis of cointegration amongst most economic time series variables:

i. the level data have no deterministic trend and the cointegrating equations have intercepts; and
ii. the level and the cointegrating equations have linear trends.

Table 1 shows that the hypothesis of the expected values of the first differences of the series is equal to zero can not be rejected; hence, there is no evidence of linear deterministic trends in the data. The graphs in Figure 1a support this conclusion. Therefore, we conclude that the cointegrated VAR model should be formulated according to i), with the constant term restricted to the cointegration space, and no deterministic trend terms. This implies that some equilibrium means are different from zero.

As can be seen in Table 4, only for the Greece-Ireland and Greece-Portugal cases does the trace test indicate the existence of one cointegrating equation at (at least) the 0.05 level. Therefore, for these two pairs we test for Granger-causality in first differences of the variables, with an error-correction term added [i. e., equations (3) and (4)], whereas for the remaining cases, we test for Granger-causality in first differences of the variables, with no error-correction term added [i. e., equations (3) and (4) with β=0]

[Insert Table 4 here]

2.4. Whole sample results

The resulting FPE statistics for the whole sample are reported in Table 5.[14]

[Insert Table 5 here]

As can be seen, in most of the cases our results suggest bidirectional Granger causality. We do not find unidirectional Granger causality relationships running from Greece to Spain or from Portugal to Ireland.

[14] These results were confirmed using both Wald statistics to test the joint hypothesis $\hat{\gamma}_1 = \hat{\gamma}_2 = ... = \hat{\gamma}_n = 0$ in equation (4) and Williams-Kloot test for forecasting accuracy (Williams, 1959). These additional results are not shown here to save space, but they are available from the authors upon request.

Note that, even though the results of the cointegration tests reject (with only two exceptions) a long-run relationship between them, we find evidence of strong causal linkages between peripheral EMU yields. Therefore, each yield series contains useful information that is not present in the others which can help to explain the others' short-run evolution. This finding may indicate that peripheral EMU countries are considered by market participants as a group, confirming earlier evidence of market segmentation between core and peripheral EMU countries (see, e.g., Sosvilla-Rivero and Morales-Zumaquero, 2011).

2.5. Rolling regression results

In this sub-section, we use rolling analysis to gain further insights into the dynamic causality between the 10 possible relationships in peripheral EMU yields. Specifically, we report the results of estimates from a sequence of short rolling samples to track a possibly time-varying relationship. We carry out 33,486 regressions using a window of 200 observations[15]. In each estimation, we apply Hsiao (1981)'s sequential procedure outlined above to determine the optimum FPE (m, 0) and FPE (m, n) statistics in each case.

A graphic presentation of the evolution of the difference between FPE (m, 0) and FPE (m, n) statistics in each case is shown in Figure 2. These graphs provide us with a view of the dynamic influence of each EMU peripheral yield over the other four and constitute our indicator of time-varying causality. Adopting a forward-looking framework, we assign the computed indicator to the first date used in the rolling regressions. Therefore, the sample covers the period 1 January 1999 to 26 March 2010 in all cases, except in those pairs where Greece is present, in which case the sample runs from 1 January 2001 to 26 March 2010. Note that if the difference is positive in the case XX → YY, this indicates the existence of a statistically significant Granger causality relationship running from country XX towards country YY.

As can be seen, we find sub-periods of Granger causality in all pair-wise relationships, including those running from Greece to Spain and from Portugal to Ireland, even though these relationships were rejected in the whole sample tests.

Given that there is no consensus on exactly what constitutes contagion or how it should be defined, in our analysis we define contagion episodes in a restrictive way as sub-periods of significant increase in causality. As a rule of the thumb, we identify such sub-periods of intense

[15] To the best of our knowledge, there is no statistical method to set the optimal window size. The chosen value of 200 observations is representative of the one used in practice and seems appropriate for our empirical application since it represents 6.36% of the sample.

causality as those in which the time-varying causality indicator is greater than its average plus two standard errors[16].

The graphs in Figure 2 suggest that the contagion episodes are concentrated around the first year of the existence of the EMU in 1999, the introduction of euro coins and banknotes in 2002, and the global financial crisis of the late-2000s. As can be seen, the graphs also indicate that the causality relationships between peripheral EMU yields increased significantly during the recent crises in sovereign debt markets since 2009, providing evidence of a strengthening in the contagion between them.

[Insert Figure 2 here]

3. Determinants of contagion

3.1. Econometric methodology

We use probit models to analyze the determinants of the contagion episodes we have detected. In our case, we define a new dependent variable (y) that takes the value one if we have detected contagion and zero otherwise. The goal is to quantify the relationship between a set of instruments (X) characterizing the country issuing a given bond and the probability of contagion (y).

To this end, we adopt a specification designed to handle the particular requirements of binary dependent variables. Suppose that we model the probability of observing a value of one as:

$$\Pr(y = 1 | X, \beta) = 1 - \Phi(-X'\beta) = \Phi(X'\beta) \qquad (5)$$

where Φ is the cumulative distribution function of the standard normal distribution. As can be seen, we adopt the standard simplifying convention of assuming that the index specification is linear in the parameters so that it takes the form $X'\beta$.

[16] We perform formal tests to evaluate whether the series have the same mean during the contagion episodes detected and the rest of the observations. The results of these tests (not shown here, but available from the authors upon request) strongly reject the null hypothesis of .equal mean across sub-samples, and provide strong evidence of the presence of increased causality.

3.2. Instruments to model the time-varying contagion

According to Dornbusch, Park, and Claessens (2000), reasons for contagion can be divided into two groups: fundamental-based reasons on the one hand, and investor behavior-based reasons on the other. While fundamental-based contagion works through real and financial linkages across countries, behavior-based contagion is more sentiment-driven.

In our analysis we will use instruments that capture both kinds of reasons. Following the literature (the IMF (2010), Barrios *et al.* (2009), Mody (2009) and Bolton and Jeanne (2011) among others), in order to measure fundamental reasons of contagion we not only use instruments that gauge the country's fiscal position but also instruments that assess the foreign debt, the country's potential rate of growth, the loss of competitiveness, the private sector indebtedness and the cross-border banking system linkages. Specifically,

i) The government debt-to-GDP (GOVDEB) and the government deficit-to-GDP (DEF) are the variables used to measure the country's fiscal position. These two variables have been widely used in the literature by other authors (see, e.g., Bayoumi *et al*., 1995) and present the advantage over the credit rating that they cannot be considered *ex post* measures of fiscal sustainability. They are compiled from Eurostat, and monthly data are linearly interpolated from quarterly observations.

ii) The current-account-balance-to-GDP ratio (CAC) is the instrument used as a proxy of the foreign debt and the net position of the country towards the rest of the world. The importance of this variable has been underlined by the IMF (2010) and Barrios *et al*. (2009). This variable is drawn from the OECD and monthly data are linearly interpolated from quarterly observations.

In view of Mody (2009)'s argument that countries' sensitivity to the financial crisis is more pronounced the greater the loss of growth potential and competitiveness, we include instruments that measure these features.

iii) The leading indicator (LEA), the GDP rate of growth (GRO) and the unemployment rate (U) are the variables used to capture the country's growth potential. The leading indicator is obtained from the OECD on a monthly basis, whilst the unemployment rate and the GDP rate of growth are collected from Eurostat (in the latter case, monthly data are interpolated from quarterly observations).

iv) The Harmonized Index of Consumer Prices monthly rate of growth is the inflation rate measure (INF) we use in our analysis as a proxy of the appreciation of the real exchange rate and, thus, the country's loss of competitiveness. It is taken from Eurostat.

As we outlined in the introduction, the origin of sovereign debt crisis in Europe goes beyond the imbalances in public finances. In some countries, such as Ireland, the crisis was mainly due to the private sector, particularly the domestic housing boom which was financed by foreign borrowing (see Lane, 2011). For this reason we also incorporate instruments that capture the indebtedness of each country's private sector in the analysis.

v) These variables are: Banks' debt-to-GDP (BANDEB), non-financial corporations' debt-to-GDP (NFIDEB), and households' debt-to-GDP (HOUDEB), constructed from data obtained from the European Central Bank Statistics. In particular, we use the statistics corresponding to the Monetary Financial Institutions (MFI) balance sheets in each euro country. Thus, household debt corresponds to the total loans to households from MFIs. To isolate it from the intermediation effect that would inflate debt ratios, banks' debt is constructed by subtracting M3, banks' remaining liabilities and banks' capital and reserves from total MFI liabilities[17]. And non-financial corporation debt is built up by adding non-financial corporation securities to total loans to non-financial corporations from MFIs[18].

[Insert Table 6 here]

Table 6 shows that after the subprime crisis in August 2007, not only does the government level of indebtedness increase in the euro area (the ratio over the GDP achieves levels of 143%, 119%, 96%, 93% and 63% at the end of December 2010 in Greece, Italy, Ireland, Spain and Portugal, respectively) but private borrowing also registers a sizeable increase. In particular, as can be observed, at the end of 2010, banks' debt-to-GDP is huge in Ireland (729%), but is also high in Portugal, Spain and Greece (182%, 159% and 98%). On the other hand, households' debt-to-GDP surpasses the 80% threshold in Ireland, Portugal and Spain, whilst non-financial corporations' debt-to-GDP is close to 90% in Portugal and Spain and around 70% in Ireland.

[17] The banks' debt variable we have constructed avoids the effects of intermediation, even though it can only be considered as an approximation of its real value, and some caveats are in order: specifically, some deposits will appear as debt (those not included in M3) and some debt securities will not be considered debt (those included in M3).

[18] Non-financial corporations' (NFCs) debt should also include "net equity of households" (liabilities of NFCs from direct pension commitments to their employees). Nevertheless, we have ignored this variable since it was not available for all the countries in the sample.

Thus, during the period 2007-2010, whereas the government debt-to-GDP ratio registers the highest increases compared to the period 2002-2006 in Ireland, Portugal and Greece (39%, 15% and 9%), there is a much steeper rise in the banks' debt-to-GDP ratio which is higher than 150% in Greece, close to 70% in Ireland, around 64% in Spain and close to 40% in Portugal. Besides, households' debt-to-GDP ratio registers an increase close to 30% in Greece, close to 20% in Ireland and Spain and around 15% in Italy, whilst non-financial corporations' debt-to-GDP ratio rises close to 30%, 25% and 20% in Ireland, Spain and Greece respectively.

Following Bolton and Jeanne (2011) and Allen *et al*. (2011), in our analysis we include variables that capture the important cross-border banking system linkages in euro area countries. These cross-border banking linkages are measured using the consolidated claims on an immediate borrower basis of Bank for International Settlements (BIS) reporting banks in the public, banking and non-financial private sectors as a proportion of GDP.

vi) In particular, we include foreign bank claims on government debt-to-GDP (PUB), on bank debt-to-GDP (BAN) and on non-financial private sector debt-to-GDP (PRI). These variables are constructed from information provided by the Bank for International Settlements and the OECD.

vii) Moreover, we explore the role of consolidated claims on an immediate borrower basis provided by BIS by nationality of reporting banks as a proportion of total foreign claims on each country. This variable is denoted as XXYYBAN, meaning the percentage of country XX's foreign claims held by country YY's banks.

[Insert Table 7 here]

The figures in Table 7 underline the fact that the causes of the debt crises that led to subsequent rescues in Europe varied substantially according to country. Greek fiscal deficit and public debt to GDP were close to 15% and 130% at the end of 2009 as a result of chronic macroeconomic imbalances. Besides, on average, foreign banks' claims on its public sector debt represented around 30% of its GDP during the period 2005-2010. Conversely, in Ireland, the crisis was mainly due to the private sector, particularly the domestic housing boom which was financed by foreign borrowing. In particular, the amount of bank and non-financial enterprise debt claimed by foreign banks is huge during the period 2005-2010 (102% and 216% of its GDP, on average). Finally, in Portugal, markets were mostly worried about the country's high external debt, specifically, that of its non-financial corporations. During the 2005-2010 period, foreign banks' claims on Portuguese enterprises surpassed 40% of the country's GDP.

As stated before, the Bank for International Settlements also provides information about the country of origin of the foreign claims. This information is displayed in Table 8.

[Insert Table 8 here]

The information provided in Table 8 is very useful for understanding the channels of contagion of debt crises through the banking system. It can be observed that at the end of 2010 French and German banks were the most exposed to foreign Greek debt, holding 39.6% and 23.7% of total foreign Greek claims respectively. In the case of Ireland, the maximum risk was borne by British banks (29.9%) followed by the Germans (26.13%). A Portuguese default would be especially harmful for Spanish banks which hold 41.9% of Portuguese banks' total claims. Finally, around 45% of Spanish and Italian foreign claims are held by French and German banks.

Finally, as we above mentioned, we also introduce an instrument that might capture investor behavior-based reasons of contagion.

viii) We use the credit rating as a proxy of the default risk (RAT). Standard &Poor's, Moody's and Fitch ratings for each government's debt are compiled from Bloomberg. Following Blanco (2001), we build up a scale to gauge the effect of investor sentiment based on the rating offered by the three agencies[19].

3.3. Empirical results

Given that the instruments used as dependent variables are published each month, we need to compute the dependent variable in the probit models on a monthly basis. To do so, we first assign a value of 1 to the daily observation if the time-varying causality indicator is greater than its average plus two standard errors. In the second step, we compute the monthly data by averaging the daily observation and assigning a value of 1 if the resulting monthly average is greater than 0.5 (i. e., if at least for half of the month there is evidence of contagion).

In Table 9 we report the results of the probit models estimated by maximum likelihood for the sample period March 2005 to March 2010[20]. The z-statistics in that table are based on robust standard errors computed using the Huber-White quasi-maximum likelihood method.

[19] By construction, the higher the scale, the worse the rating categories.

[20] The reduction in the sample period is imposed by the availability of data regarding the consolidated claims of Bank for International Settlements' reporting banks on each sector.

[Insert Table 9 here]

The analysis of the coefficient values is complicated by the fact that coefficients estimated from a binary model cannot be interpreted as the marginal effect on the dependent variable. Nevertheless, the direction of the effect of a change in any instrument depends only on the sign of the coefficient estimated: positive values imply that an increase in a given instrument will raise the probability of contagion, while negative values indicate the opposite.

Interestingly, the variable XXYYBAN is statistically significant in all cases; suggesting that, in a scenario of increased cross-border financial activity in the euro area, contagion of the crisis in one country to other countries through the banking system can be a major issue.

Regarding the measures of the country's fiscal position, our results indicate that both GOVDEB and DEF are key determinants of the probability of a contagion episode. As for the instruments used to gauge the level of competitiveness of a given country, our estimations suggest that both CAC and INF are statistically significant with the expected sign. In particular, they are extremely useful when explaining the contagion from Greece, Spain and Portugal. In relation to the variables used to capture the country's growth potential, we find a positive influence for U and a negative effect for LEA and GRO, suggesting that the stronger the economy, the lower the probability of contagion in debt markets. This conclusion is particularly relevant in the case of Greece, Italy and Portugal.

With regard to the role of private debt, we find empirical evidence supporting its importance in the cases of Spain and Italy. Interestingly, this variable is not significant in the case of Ireland, even though some authors have claimed that it was the main cause of the debt crisis in this country. Nevertheless, we detect a major effect of foreign bank claims on banking and non-financial private sector debt-to-GDP on the probability of contagion from Ireland. This finding seems to underline the dependence of Ireland's domestic expansion on foreign borrowing.

Finally, as regards the impact of investor sentiment, the credit rating scale seems to be an important determinant in six out of the 20 cases considered.

In Table 9 we report the McFadden R-squared as a measure of goodness of the fit. As can be seen, it ranges from 0.5595 to 0.8388, suggesting the relative success of the probit regression models in predicting the values of the dependent variable within the sample. As a further test to evaluate how well our estimated probit models fit the observations, we compute the fitted probability both within-sample and out-of-sample. Recall that when generating our contagion indicator, we left out nine observations (April to December 2010) that were not used in the estimation. This allows us to evaluate the out-of-sample performance of the estimated probit models based on the actual evolution of the instrumental variables. Figure 3 reports the results.

[Insert Figure 3 here]

As can be seen, the fitted probabilities closely track the evolution of the observed within-sample probabilities. Regarding the out-of-sample probabilities, our results suggest the occurrence of an additional contagion episode in the last months of 2010 coinciding with a period of renewed turbulence in European debt markets.

4. Concluding remarks

This paper presents a dynamic approach to the analysis of the evolution of the degree of causality and contagion between peripheral EMU public debt markets (Greece, Ireland, Italy, Portugal and Spain). To this end, we have (1) tested for the existence of possible causal relationships between the evolution of the yield of these countries' issues, (2) examined the time-varying nature of these causal relationships to detect episodes of contagion between them, and (3) analyzed the determinants of these contagion events.

It seems increasingly clear that the origin of sovereign debt crisis in Europe has gone beyond the imbalances in public finances and that there is also an obvious interconnection between public and private debt. As a result, we have analyzed the role of this interconnection in the episodes of contagion by using a unique dataset on private debt-to-GDP by sector (households, banks and non-financial corporations) in each peripheral EMU country. Besides, since the reasons for contagion can be fundamental-based or investor behavior-based, we have included instruments that capture both types. In addition, we have borne in mind that fundamental-based contagion works not only through real linkages, but also through financial linkages across countries. Specifically, in the current scenario of increased cross-border financial activity in the euro area, special attention has been paid to the impact of the degree of integration of the banking system on the speed at which a sovereign crisis in a country can spill over to others. This channel of contagion has generally been ignored by the recent literature, but its relevance is crucial.

The main results of our analysis can be summarized as follows. Firstly, the results of the rolling analysis we apply in order to explore the dynamic causality between peripheral EMU yields suggest that there exist sub-periods of Granger causality in all pair-wise relationships. Given the absence of consensus in the literature on how contagion should be defined, we have identified contagion episodes as sub-periods of significant increase in causality. Hence, our empirical evidence suggests that these episodes are concentrated around the first year of the launch of the EMU in 1999, the introduction of euro coins and banknotes in 2002 and the global financial crisis in the late-2000s. Our results also indicate that the causality relationships between peripheral EMU yields have been significantly reinforced during the recent crises in sovereign debt markets since 2009, providing evidence of an increase in the contagion between them.

Secondly, the results of the probit models estimated to analyze the determinants of the previously detected contagion episodes indicate that in all cases the variable that captures cross-border banking linkages is statistically significant. This finding suggests that, in a scenario of increased international financial activity in the euro area, contagion of the crisis in one country to other countries through the banking system may be an important issue. It is important to recall that macroeconomic imbalances in a specific country (the instruments we have used to capture them also indicate that they are key determinants of the probability of occurrence of a contagion episode) lead to rising sovereign spreads and a devaluation of the government debt that is mirrored in banks' balance sheets. Lastly, regarding the role of private debt, we find evidence of its importance in the cases of Spain and Italy. However, we detect a major effect of foreign bank claims on banking and non-financial private sector debt-to-GDP on the probability of contagion from Ireland, which seems to underline the dependence of Ireland's domestic boom on foreign borrowing.

In the current context of uncertainty in European sovereign debt markets, the analysis presented in this paper deals with a subject that has not been addressed in sufficient depth by the literature and is of particular relevance both to academics and to policy-makers.

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ANNEX

Figure 1a. Daily 10-year sovereign yields in peripheral EMU countries: 1999-2010

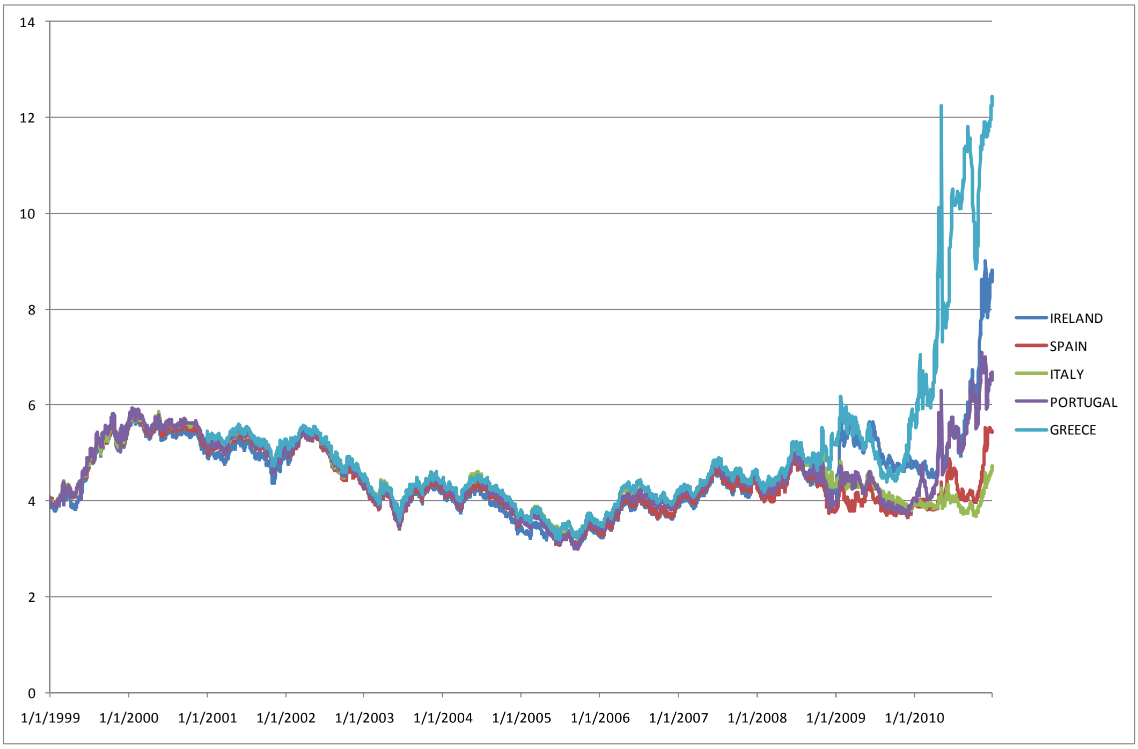


Figure 1b. Daily 10-year sovereign yield spreads over Germany: 1999-2010

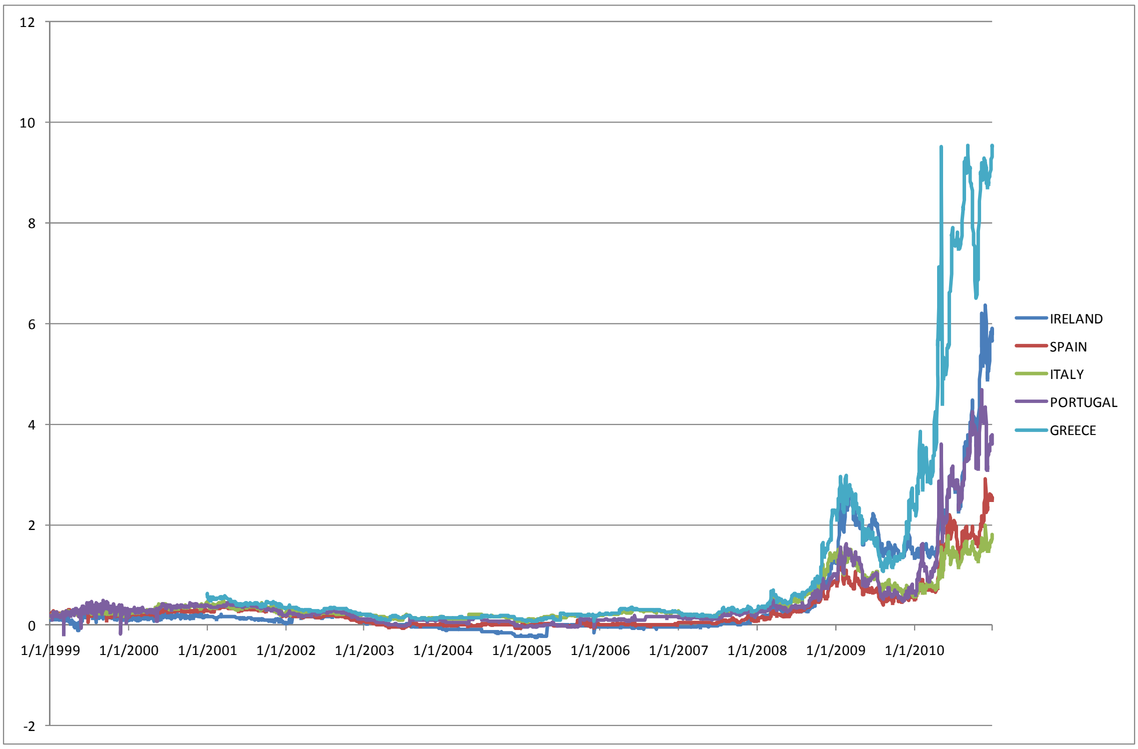
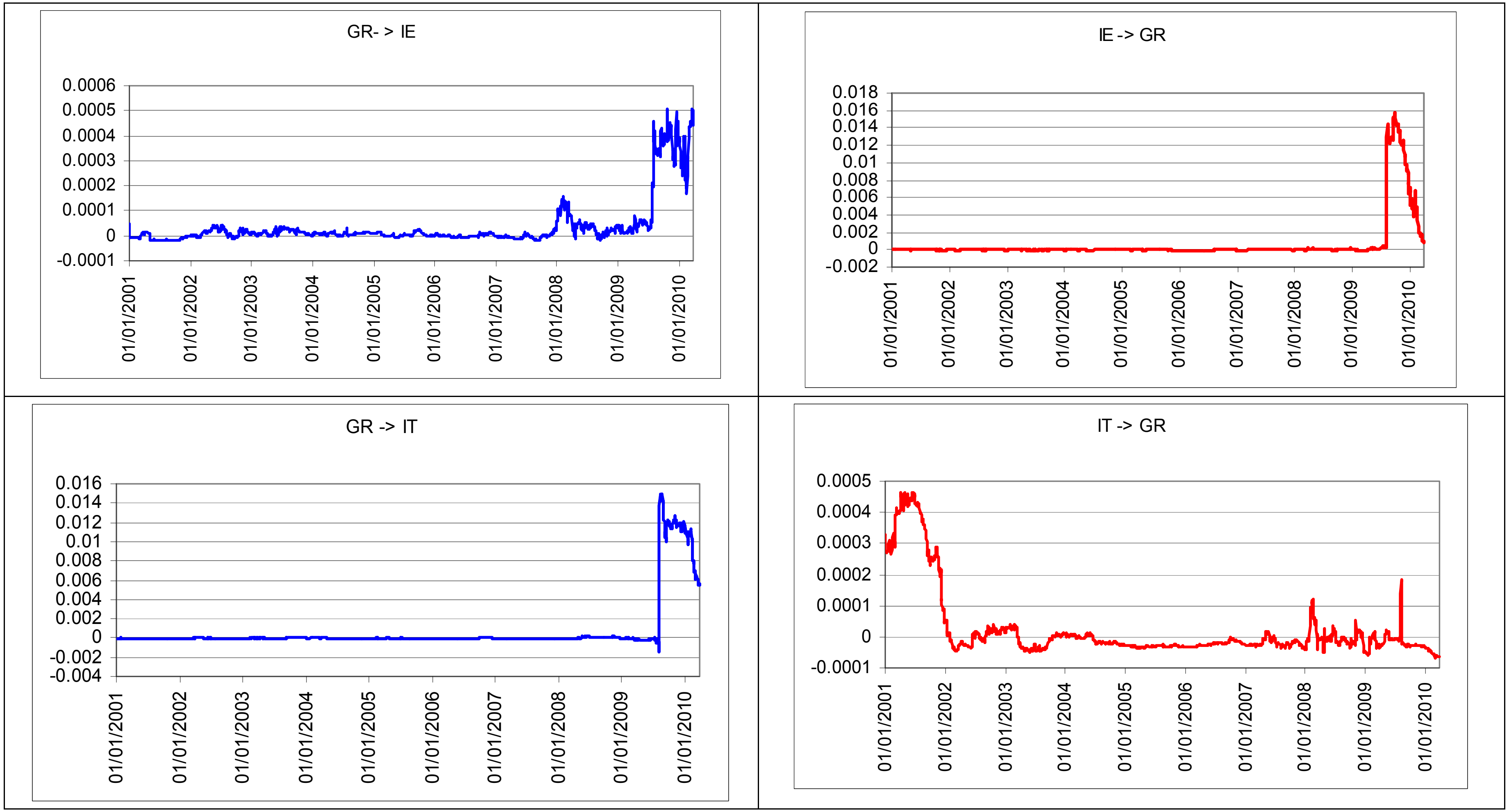
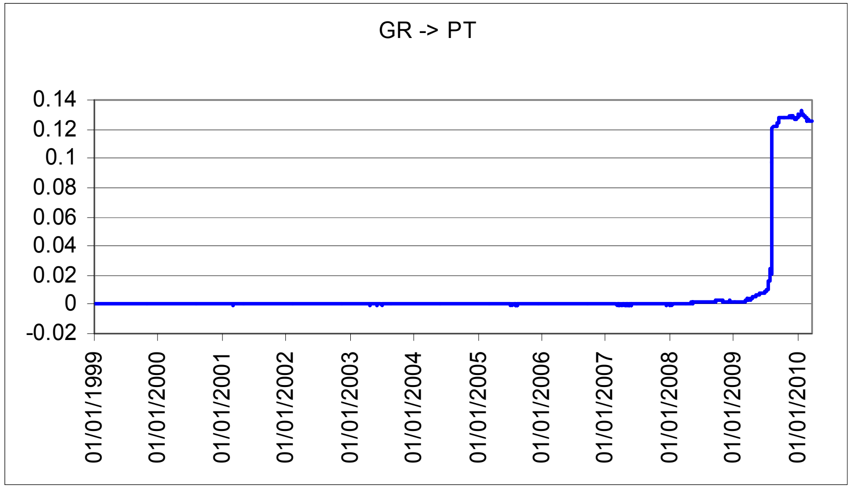


Figure 2: FPE sequence from rolling regressions

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0.1
0.08
0.06
0.04
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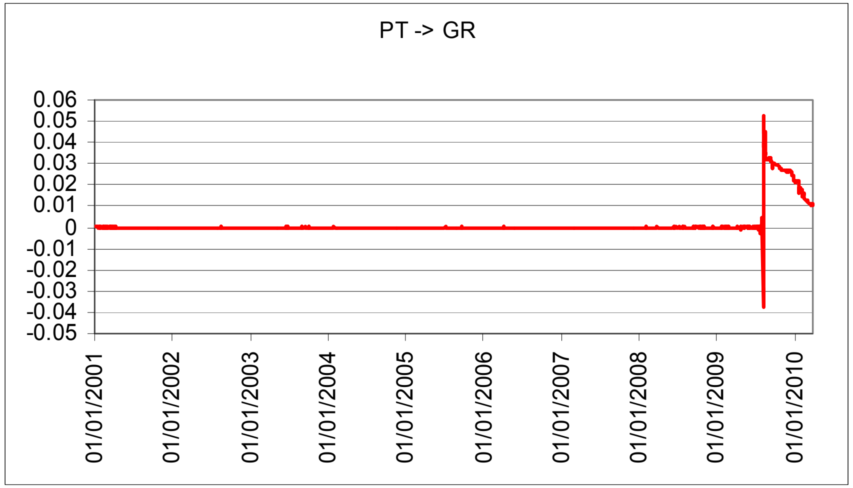
01/01/2010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-0.01
-0.02
-0.03
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-0.05
01/01/2001
01/01/2002
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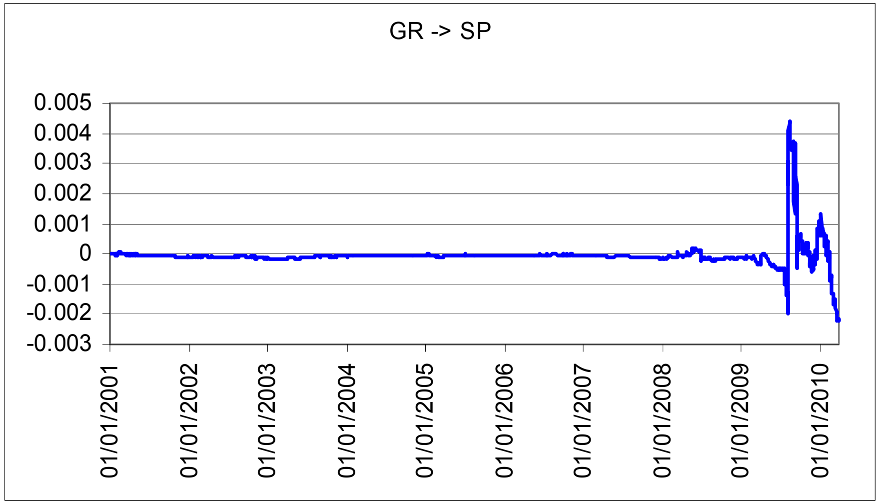
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-0.003
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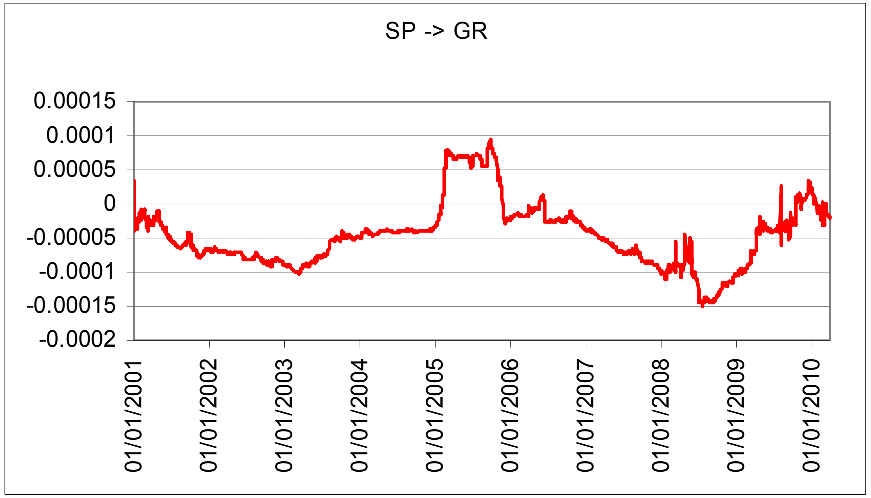
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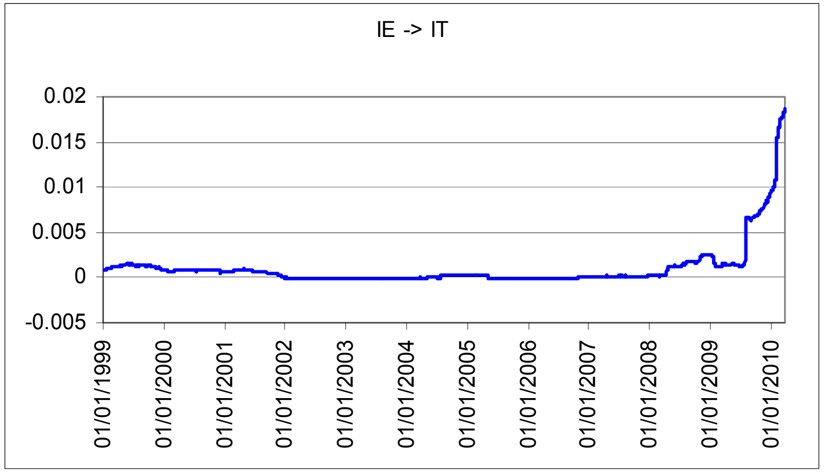
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0
-0.005
01/01/1999
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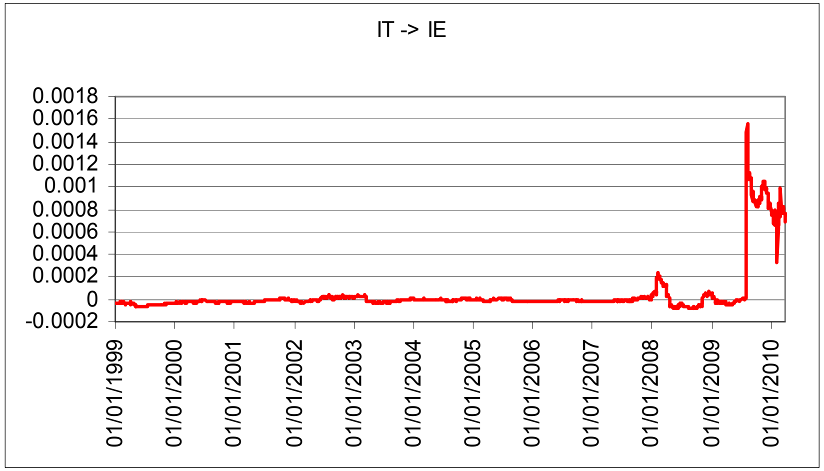
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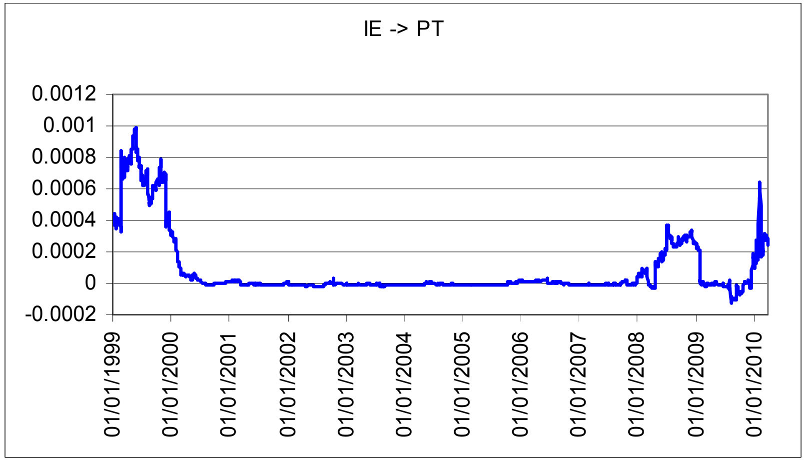
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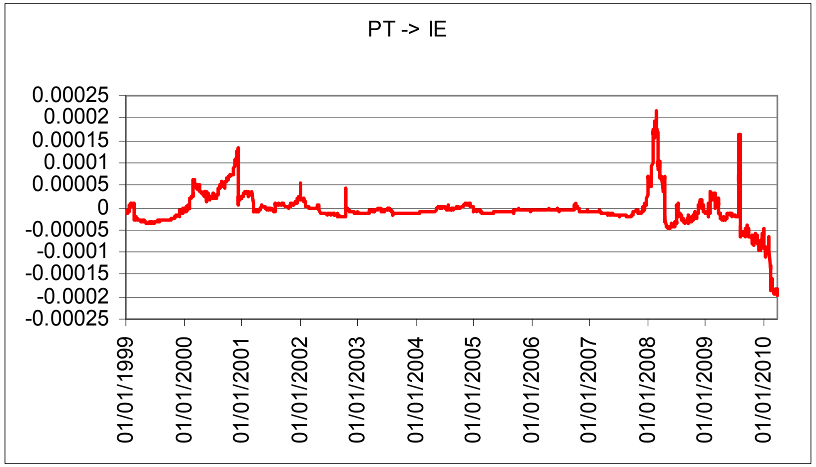
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01/01/2000
01/01/2001
01/01/2002
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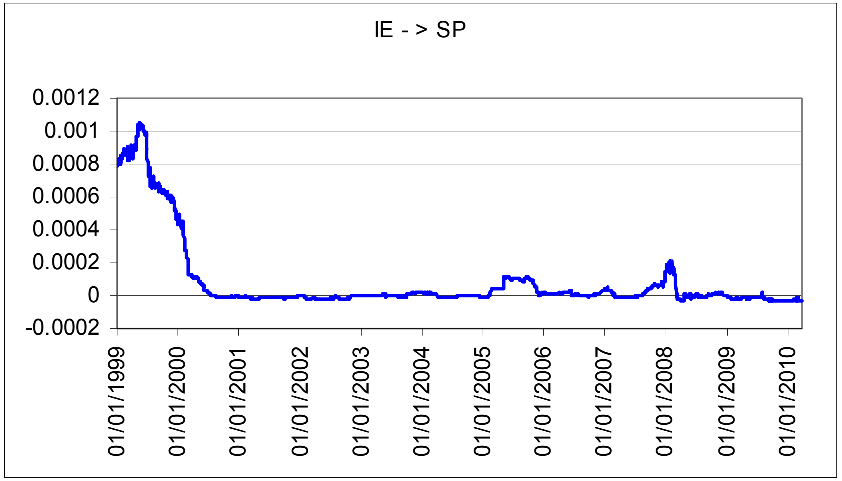
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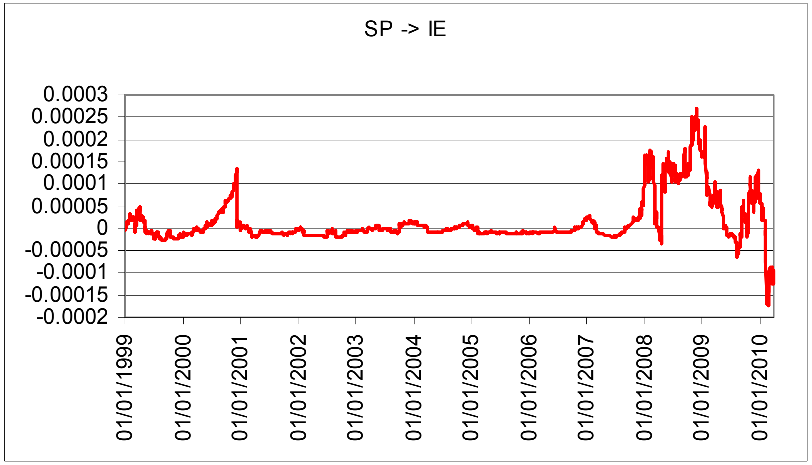
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-0.0001
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-0.0002
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01/01/2000
01/01/2001
01/01/2002
01/01/2003
01/01/2004
01/01/2005
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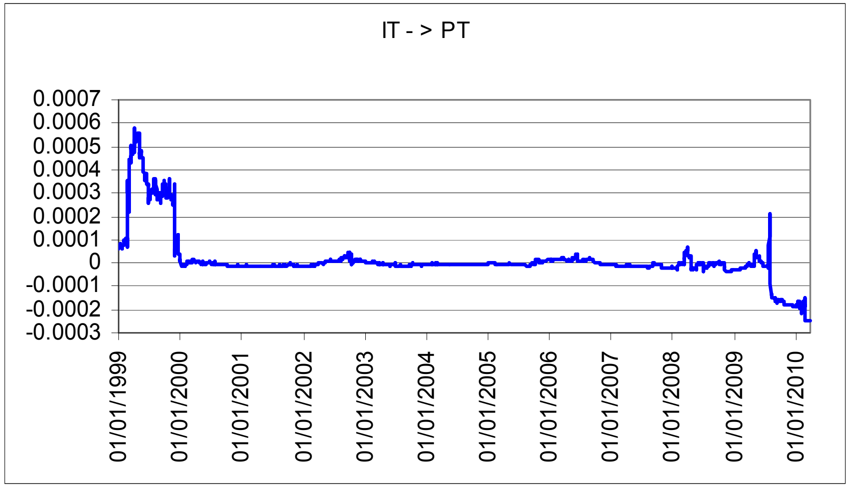
01/01/2009
01/01/2010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01/01/2001
01/01/2002
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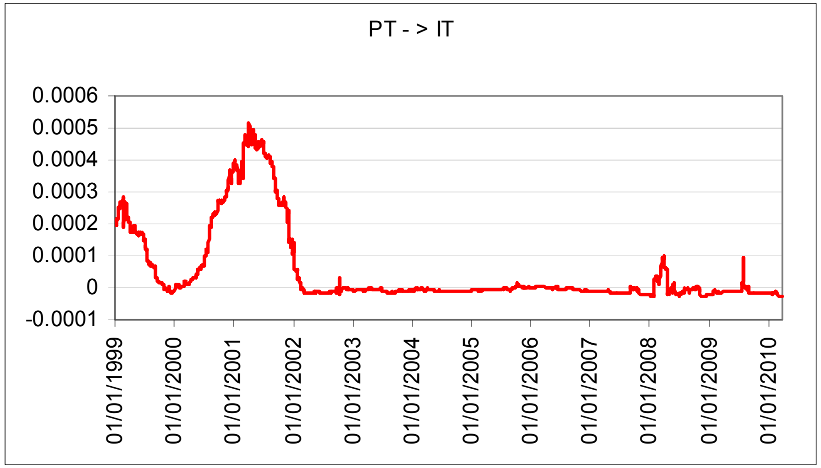
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0
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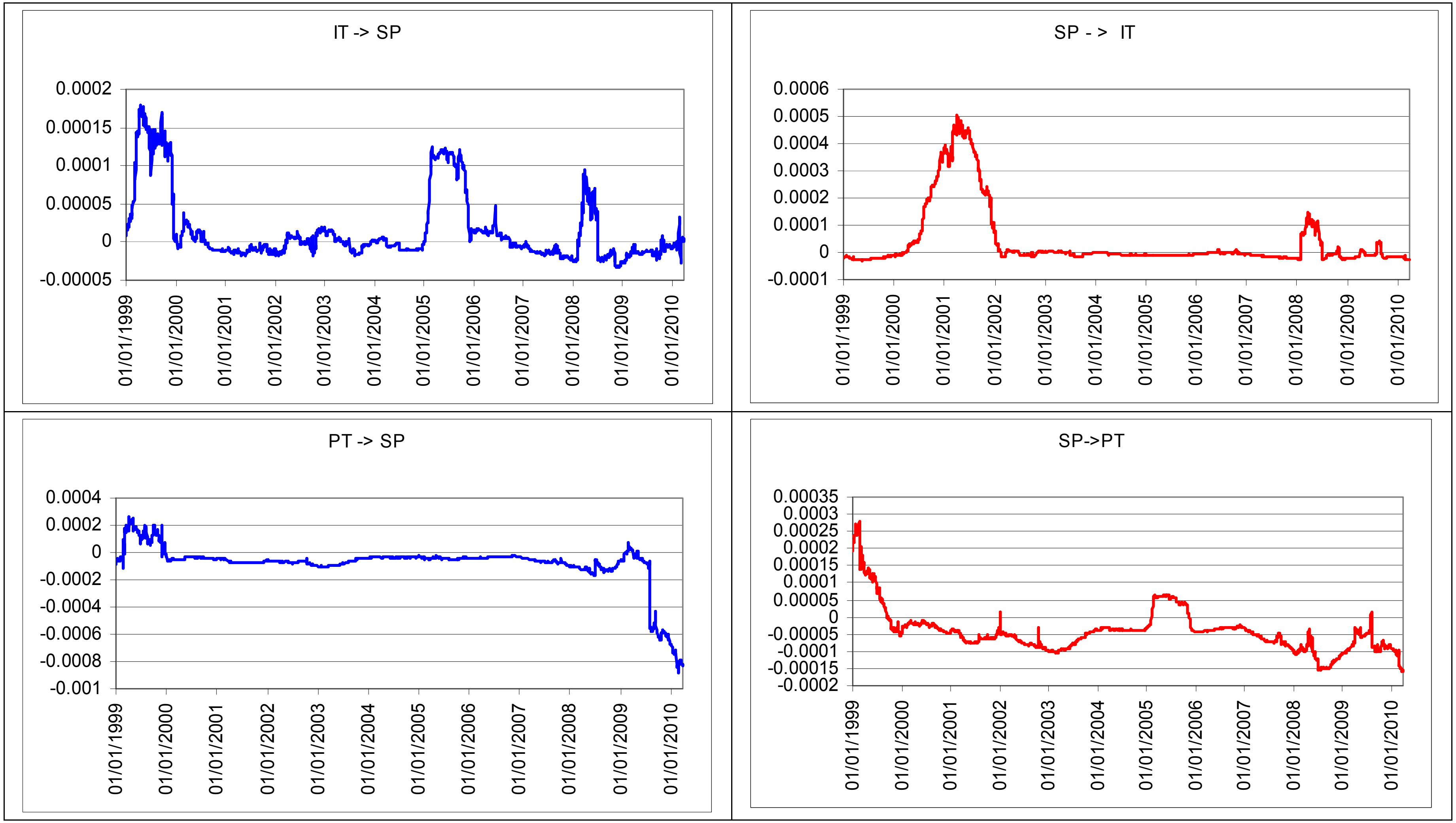
01/01/2010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01/01/2003
01/01/2004
01/01/2005
01/01/2006
01/01/2007
01/01/2008
01/01/2009
01/01/2010
SP - > IT
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
-0.0001
PT -> SP
0.0004
0.0002
0
-0.0002
-0.0004
-0.0006
-0.0008
-0.001
SP->PT
0.00035
0.0003
0.00025
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0.0001
0.00005
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-0.00005
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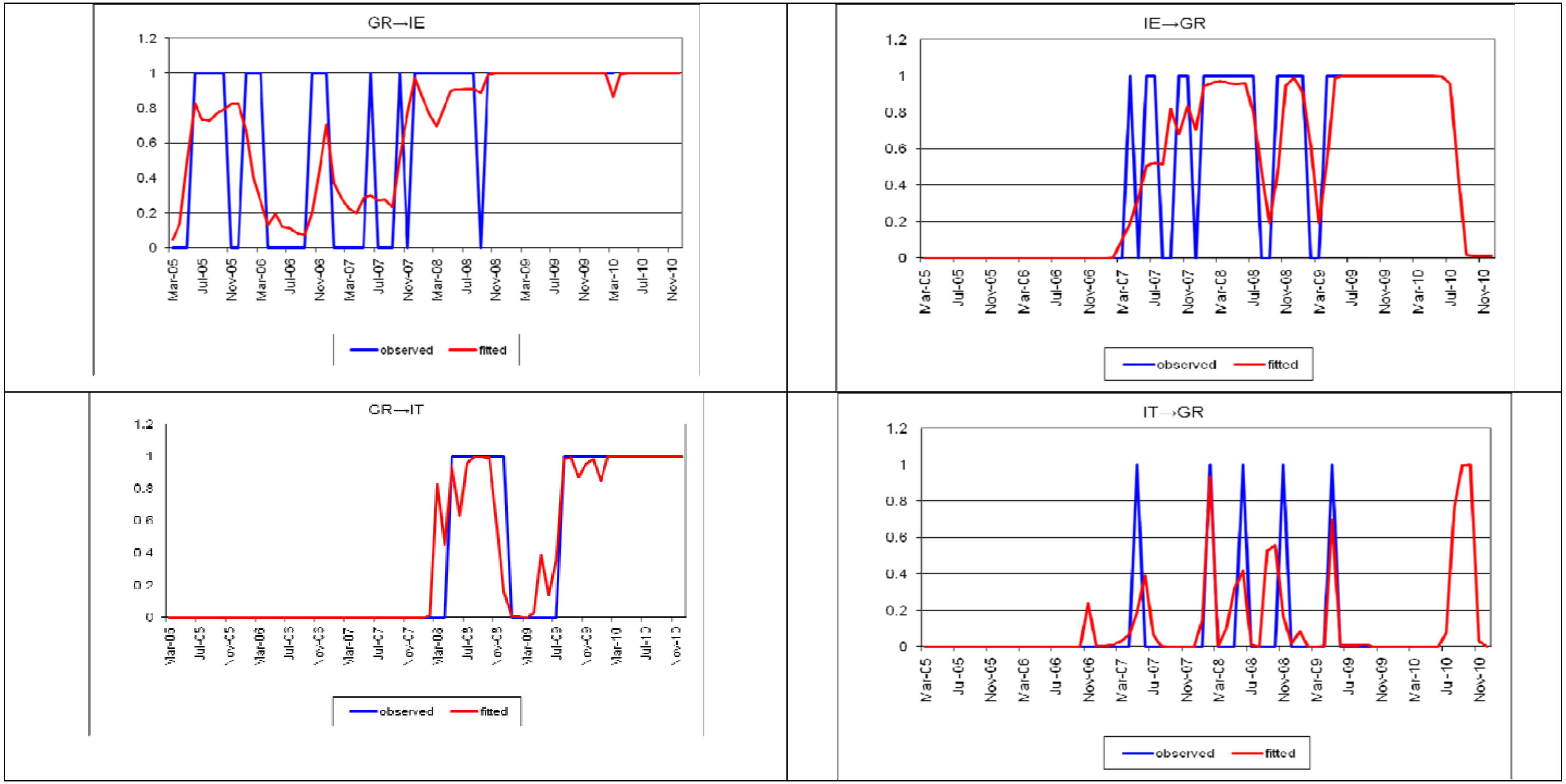
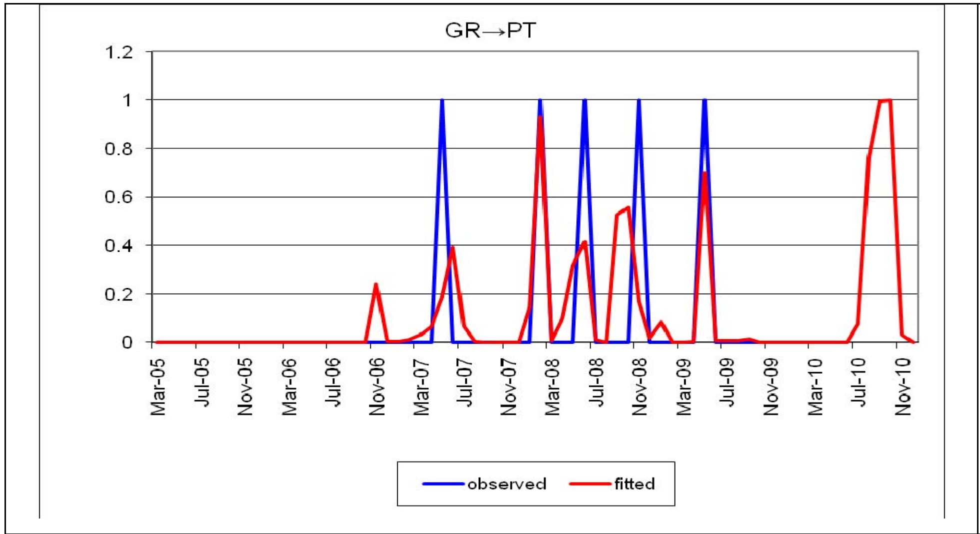
-0.00015
-0.0002

Figure 3: Probit results




GR→PT
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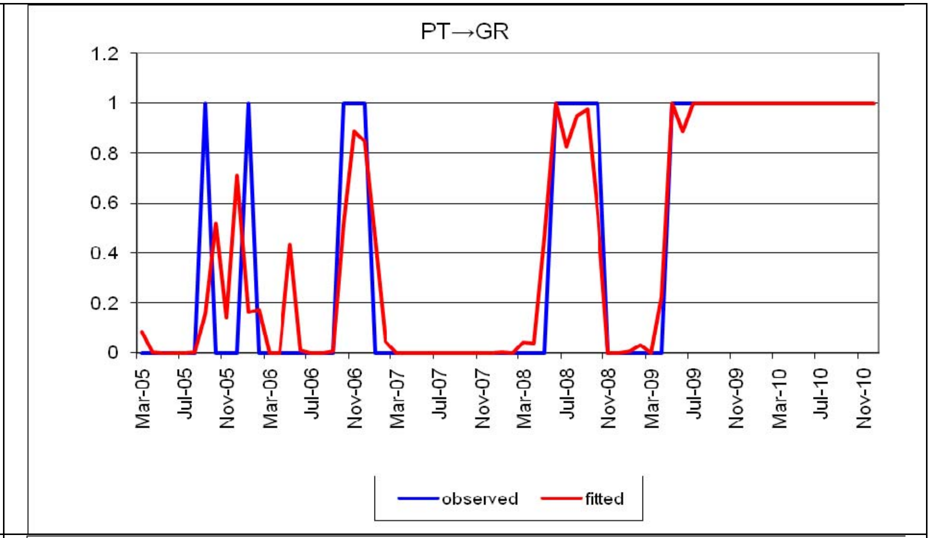
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted


PT→GR
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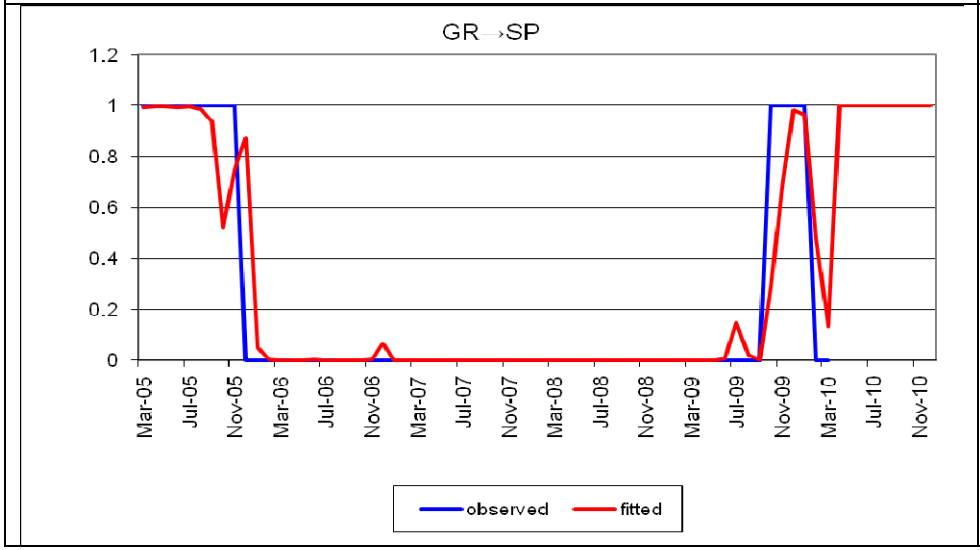
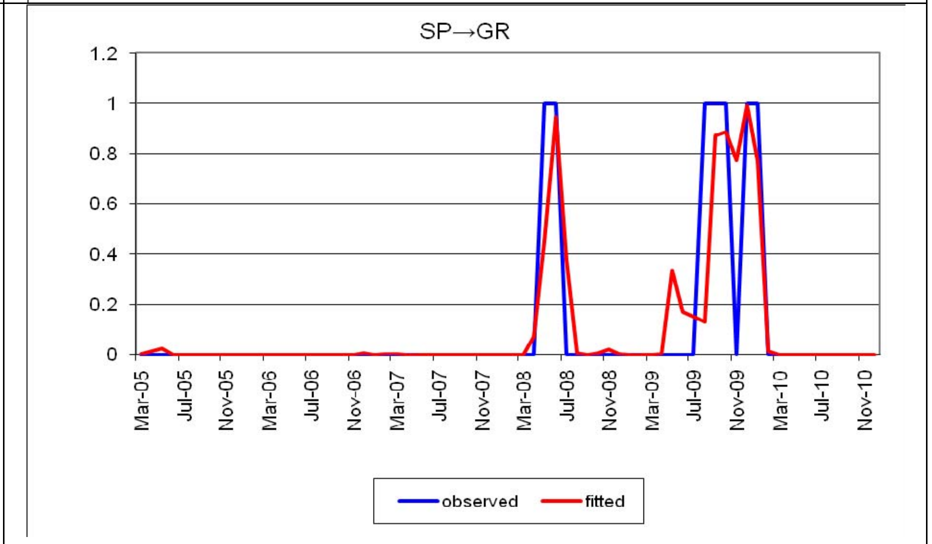
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted


GR →SP
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted


SP→GR
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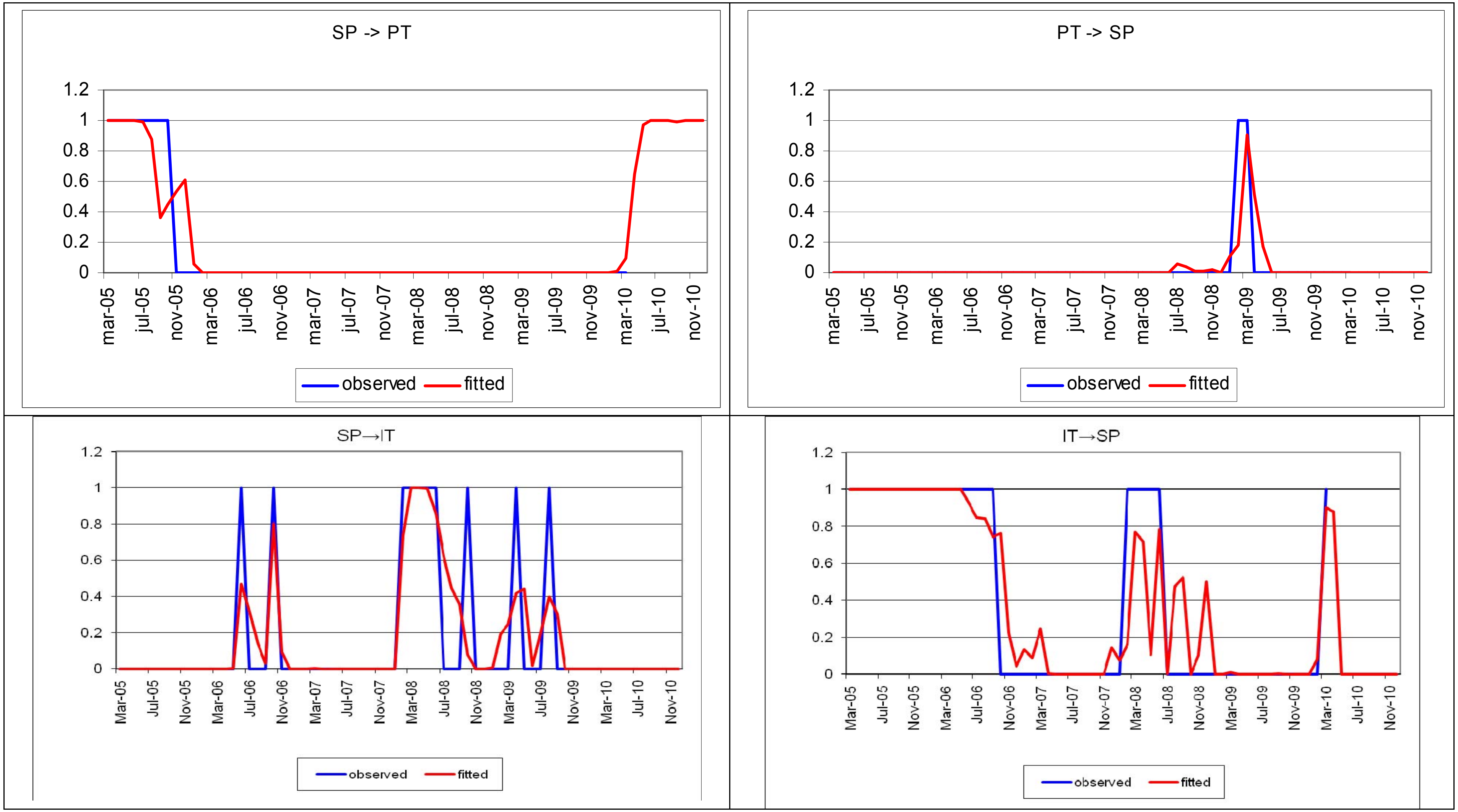
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted


SP -> PT
1.2
1
0.8
0.6
0.4
0.2
0
mar-05
jul-05
nov-05
mar-06
jul-06
nov-06
mar-07
jul-07
nov-07
mar-08
jul-08
nov-08
mar-09
jul-09
nov-09
mar-10
jul-10
nov-10
observed
fitted
PT -> SP
1.2
1
0.8
0.6
0.4
0.2
0
mar-05
jul-05
nov-05
mar-06
jul-06
nov-06
mar-07
jul-07
nov-07
mar-08
jul-08
nov-08
mar-09
jul-09
nov-09
mar-10
jul-10
nov-10
observed
fitted
SP→IT
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
Nov-06
Mar-07
Jul-07
Nov-07
Mar-08
Jul-08
Nov-08
Mar-09
Jul-09
Nov-09
Mar-10
Jul-10
Nov-10
observed
fitted
IT→SP
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05
Jul-05
Nov-05
Mar-06
Jul-06
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Mar-07
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Jul-09
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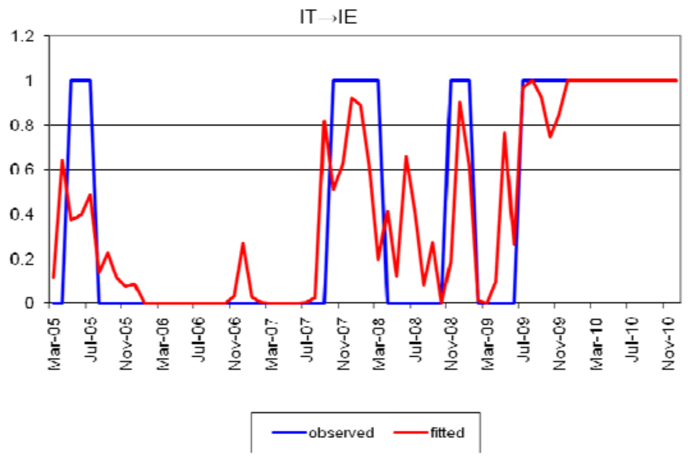
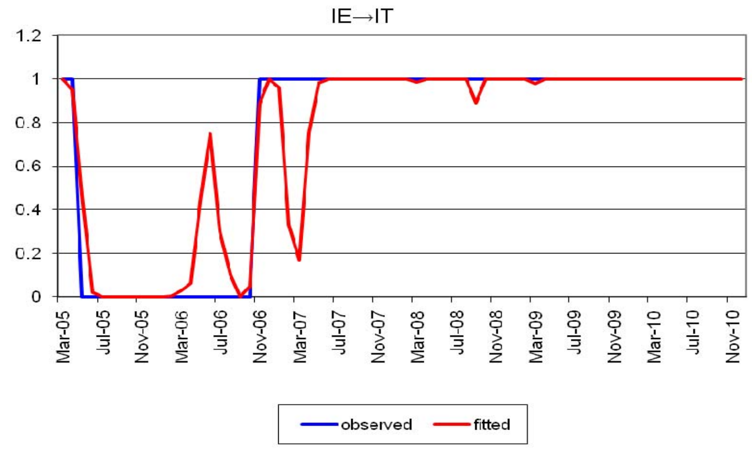
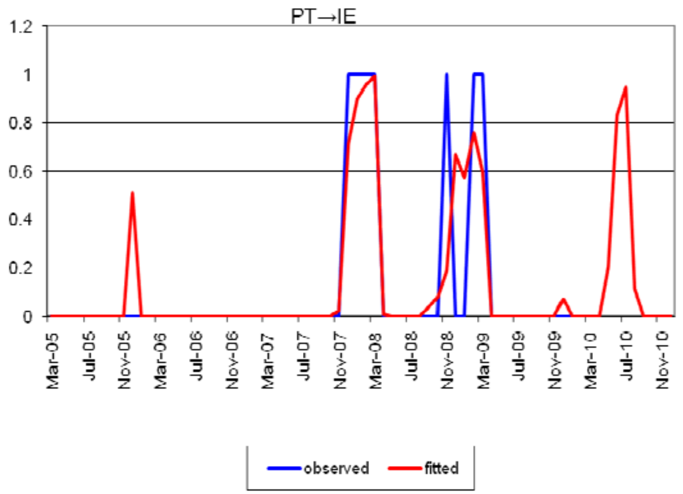
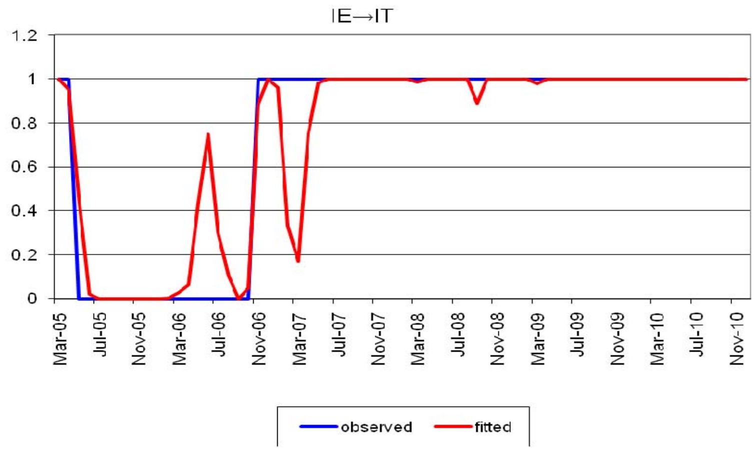
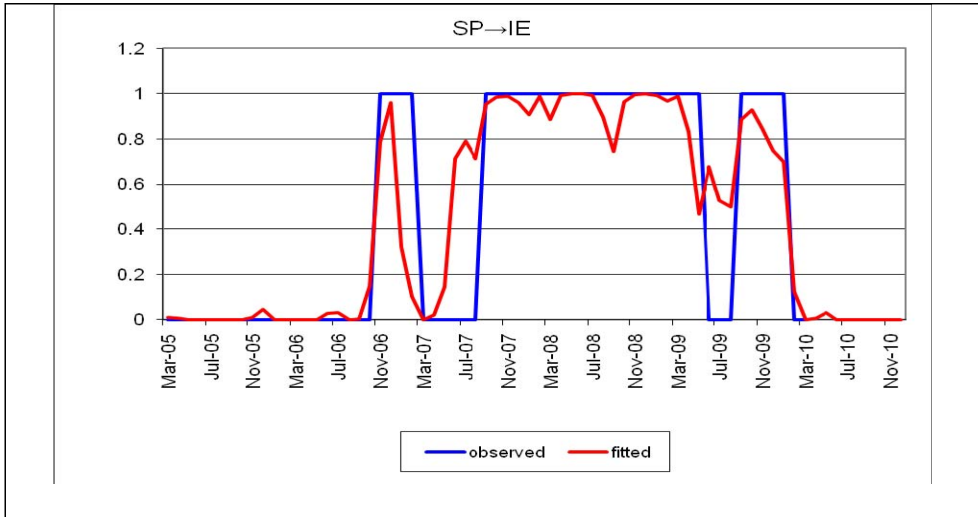
Nov-10
observed
fitted

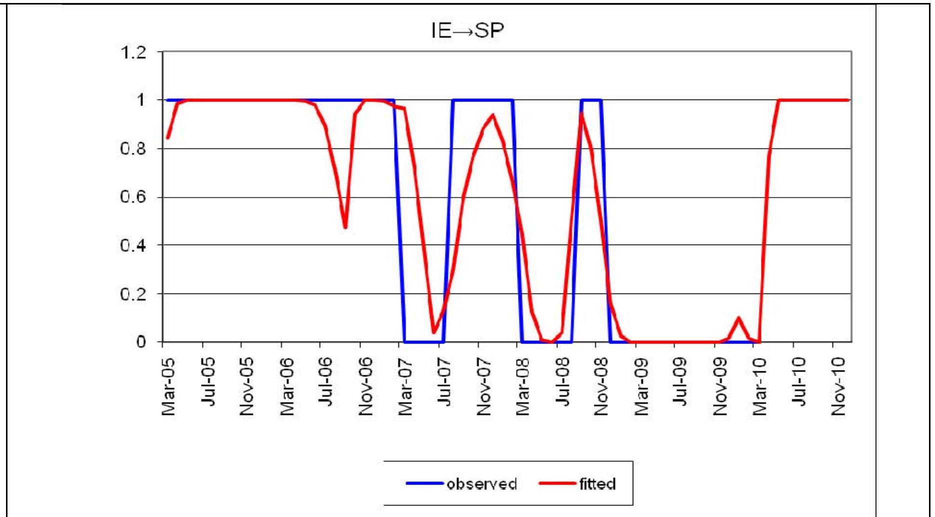

IT→IE
observed
fitted

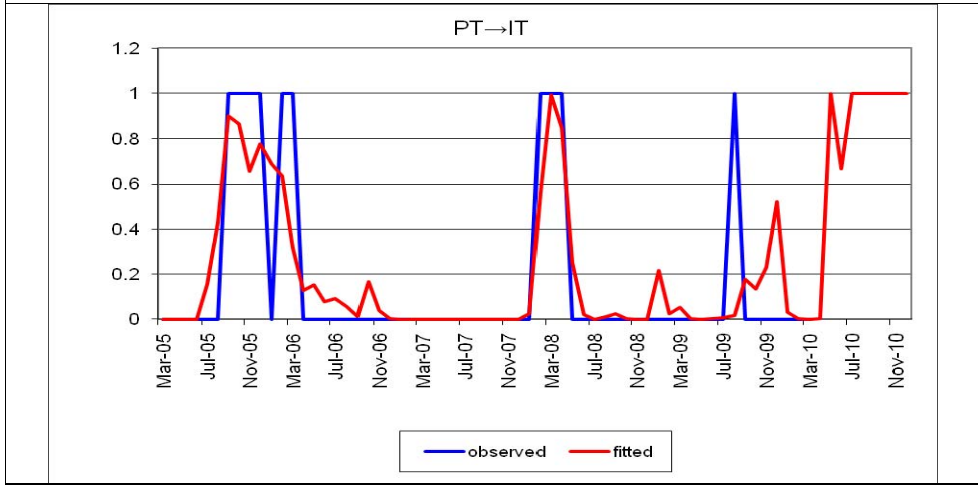

IE→IT
observed
fitted


PT→IE
observed
fitted


IE→IT
observed
fitted


SP→IE
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted


IE→SP
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted


PT→IT
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted

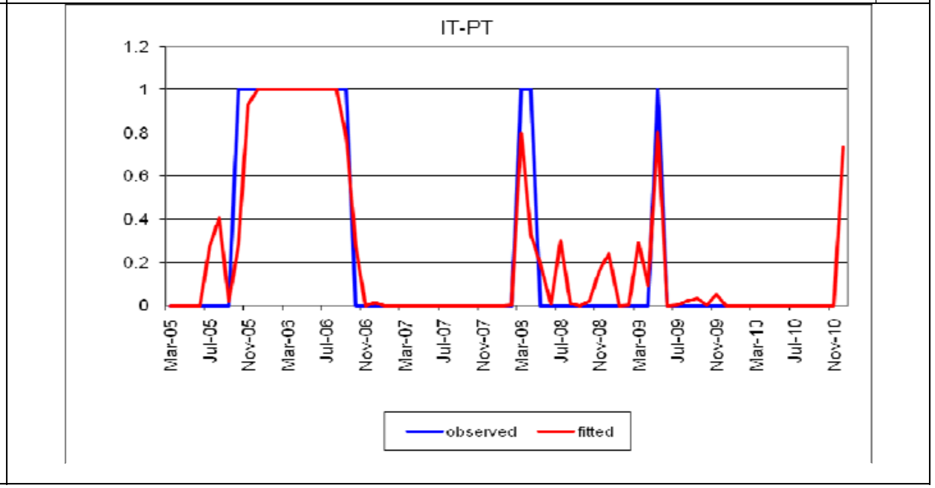

IT-PT
1.2
1
0.8
0.6
0.4
0.2
0
Mar-05 Jul-05 Nov-05 Mar-06 Jul-06 Nov-06 Mar-07 Jul-07 Nov-07 Mar-08 Jul-08 Nov-08 Mar-09 Jul-09 Nov-09 Mar-10 Jul-10 Nov-10
observed
fitted

Table 1. Descriptive statistics

Panel A: Levels	GR	IE	IT	PT	SP
Mean	4.995	4.543	4.491	4.541	4.379
Median	4.544	4.459	4.374	4.405	4.232
Maximum	12.440	9.012	5.879	7.104	5.870
Minimum	3.206	3.038	3.215	2.997	3.025
Std. Dev.	1.637	0.828	0.615	0.722	0.650
Skewness	2.714	1.236	0.343	0.423	0.376
Kurtosis	10.589	7.304	2.268	2.793	2.230
Jarque-Bera	9468.5	3213.9	131.5	99.0	151.2
Observations	2610	3131	3131	3131	3131
Panel B: First differences					
	DGR	**DIE**	**DIT**	**DPT**	**DSP**
Mean	0.003	0.002	0.000	0.001	0.000
Median	0.000	0.000	0.000	0.000	0.000
Maximum	1.304	0.682	0.213	0.546	0.253
Minimum	-4.323	-1.028	-0.319	-1.470	-0.441
Std. Dev.	0.117	0.058	0.041	0.062	0.044
Skewness	-17.879	-1.162	0.181	-4.230	-0.077
Kurtosis	720.496	48.784	5.562	113.490	7.960
Jarque-Bera	56102048.0	274076.8	873.0	1601451.0	3211.0
Observations	2609	3130	3130	3130	3130

Note: In all tables GR, IE, IT, PT and SP stand for Greece, Ireland, Italy, Portugal and Spain respectively.

Table 2. Augmented Dickey- Fuller tests for unit roots.

Panel A: I (2) versus I (1)			
	τ_τ	τ_μ	τ
DGR	-17.8072*	-17.6380*	-17.5929*
DIE	-47.7382*	-47.7020*	-47.6802*
DIT	-52.3394*	-52.3468*	-52.3535*
DPT	-31.6051*	-31.5955*	-31.5838*
DSP	-51.8722*	-51.8773*	-51.8802*
Panel B: I (1) versus I (0)			
	τ_τ	τ_μ	τ
GR	0.2766	1.2043	1.5440
IE	0.3425	0.3400	1.3145
IT	-2.6923	-2.0867	0.0225
PT	-1.0206	-1.2202	0.6855
SP	-1.8358	-1.7678	0.2859

Notes:
The ADF statistic is a test for the null hypothesis of a unit root.
τ_τ, τ_μ and τ denote the ADF statistics with drift and trend, with drift, and without drift, respectively.
* denotes significance at the 1% level. Critical values based on MacKinnon (1996)

Table 3. KPSS tests for stationarity

Panel A: I (2) versus I (1)		
	τ_τ	τ_μ
DGR	0.1052	0.2574
DIE	0.0877	0.3287
DIT	0.1083	0.1072
DPT	0.1103	0.1868
DSP	0.0975	0.1551
Panel B: I (1) versus I (0)		
	τ_τ	τ_μ
GR	0.9832*	1.8948*
IE	1.1606*	1.1528*
IT	0.6825*	2.9237*
PT	0.9373*	1.6140*
SP	0.8374*	3.0079*

Notes:
The KPSS statistic is a test for the null hypothesis of stationarity.
τ_τ and τ_μ denote the KPSS statistics with drift and trend, and with drift, respectively.
* denotes significance at the 1% level. Asymptotic critical values based on Kwiatkowski *et al.* (1992. Table 1)

Table 4. Cointegration tests

	Hypothesized numbers of cointegrating relations	Trace statistic[a]	p-value[b]
GR. IE	None At most one	20.3839** 1.0135	0.0481 0.9498
GR. IT	None At most one	16.5832 3.0084	0.1488 0.5791
GR. PT	None At most one	21.0916** 2.8721	0.0384 0.6049
GR. SP	None At most one	14.7411 2.6170	0.2416 0.6544
IE. IT	None At most one	12.6781 1.2744	0.3901 0.9118
IE. PT	None At most one	10.2764 1.7622	0.6127 0.8244
IE. SP	None At most one	9.67O6 1.0393	0.6721 0.9464
IT. PT	None At most one	9.2582 1.8854	0.7119 0.8004
IT. SP	None At most one	13.5751 2.7382	0.3197 0.6307
PT. SP	None At most one	15.5181 2.9255	0.1981 0.5947

Notes: [a] * and ** denote rejection of the hypothesis at the 1% and 5% level, respectively.
[b] MacKinnon *et al.* (1999)'s p-values.

Table 5. FPE statistics for the whole sample

	FPE(m.0)x10^{-3}	FPE(m.n) x10^{-3}	Causality
GR → IE	3.4311 (1.0)	3.3972 (1.1)	Yes
IE → GR	13.1864 (4.0)	12.8586 (4.4)	Yes
GR → IT	1.6707 (1.0)	1.6695 (1.1)	Yes
IT → GR	13.1864 (4.0)	13.0770 (4.1)	Yes
GR → PT	3.5423 (4.0)	3.5096 (4.1)	Yes
PT → GR	13.1864 (4.0)	12.6075 (4.4)	Yes
GR → SP	1.9055 (4.0)	1.9063 (4.1)	No
SP → GR	13.1864 (4.0)	13.1102 (4.4)	Yes
IE → IT	1.6910 (1.0)	1.6586 (1.1)	Yes
IT → IE	3.2584 (1.0)	3.2596 (1.1)	Yes
IE → PT	3.8007 (4.0)	3.6855 (4.1)	Yes
PT → IE	3.2584 (1.0)	3.2602 (1.1)	No
IE → SP	1.9248 (4.0)	1.8941 (4.1)	Yes
SP → IE	3.2584 (1.0)	1.9248 (1.4)	Yes
IT → PT	3.8007 (4.0)	3.7989 (4.1)	Yes
PT → IT	1.6910 (1.0)	1.6812 (1.1)	Yes
IT → SP	1.9248 (4.0)	1.9214 (4.1)	Yes
SP → IT	1.6910 (1.0)	1.6878 (1.1)	Yes
PT → SP	1.9248 (4.0)	1.9183 (4.1)	Yes
SP → PT	3.8007 (4.0)	3.7832 (4.11)	Yes

Note: The figures in brackets are the optimum order of lags in each pair of countries

Table 6. Debt-to-GDP by sector

GREECE	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average 2002-06 (I)	Average 2007-10 (II)	% (II)/(I)
Banks	24.6	26.0	25.5	28.4	33.7	48.4	63.2	68.5	97.6	27.6	69.4	151%
Households	19.5	22.6	27.0	32.6	37.0	40.4	40.8	41.5	59.9	35.7	45.6	28%
Non-financial corporations	32.6	33.2	34.0	37.5	39.0	43.1	50.9	48.0	53.0	41.3	48.8	18%
General Government	101.7	97.4	98.9	109.0	106.4	105.4	110.7	127.1	142.8	111.0	121.5	9%
IRELAND	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average 2002-06 (I)	Average 2007-10 (II)	% (II)/(I)
Banks	287.1	329.0	399.3	491.9	579.6	609.7	726.1	753.6	729.1	417.4	704.6	69%
Households	43.9	48.5	60.9	70.9	77.8	81.2	84.8	92.3	89.5	72.2	86.9	20%
Non-financial corporations	40.2	44.0	55.4	63.6	79.9	91.3	105.9	107.2	72.0	73.3	94.1	28%
General Government	30.7	31.0	29.5	27.4	24.8	25.0	44.4	65.6	96.2	41.6	57.8	39%
ITALY	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average 2002-06 (I)	Average 2007-10 (II)	% (II)/(I)
Banks	65.5	69.4	71.9	77.1	85.6	94.1	104.1	105.9	104.3	73.9	102.1	38%
Households	21.5	23.0	25.1	27.0	28.5	29.8	30.3	32.7	38.1	28.4	32.7	15%
Non-financial corporations	44.4	46.4	47.4	48.0	51.7	56.8	60.9	61.7	62.3	53.3	60.4	13%
General Government	105.7	104.4	103.9	105.9	106.6	103.6	106.3	116.1	119.0	107.9	111.3	3%
PORTUGAL	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average 2002-06 (I)	Average 2007-10 (II)	% (II)/(I)
Banks	106.3	113.3	101.6	103.8	115.3	126.4	136.6	156.3	182.5	108.1	150.4	39%
Households	59.3	58.6	60.4	64.5	70.7	74.5	78.3	81.7	82.3	70.0	79.2	13%
Non-financial corporations	68.2	67.9	67.2	70.8	72.7	78.7	90.8	93.0	90.6	77.8	88.3	14%
General Government	53.8	55.9	57.6	62.8	69.5	68.3	71.6	83.0	93.0	68.4	79.0	15%
SPAIN	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average 2002-06 (I)	Average 2007-10 (II)	% (II)/(I)
Banks	72.4	78.5	84.7	107.3	116.9	133.7	150.1	161.4	159.2	92.0	151.1	64%
Households	47.5	51.1	55.8	66.4	74.2	78.3	81.9	83.5	82.1	69.0	81.4	18%
Non-financial corporations	47.1	49.6	53.8	63.0	76.3	85.5	91.2	90.4	87.0	71.6	88.5	24%
General Government	52.5	48.7	46.2	43.0	39.6	36.1	39.8	53.3	60.1	46.6	47.3	2%

Note: Debt-to-GDP at the end of each year.
Source: Eurostat, Monetary Financial Institutions (MFIs) balance sheets obtained from the European Central Bank and authors' estimates.

Table 7. Foreign banks' claims on individual countries-to-GDP by sector.

Foreign banks' claims on public sector debt/GDP							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
GREECE	30.79	33.64	36.07	30.56	29.93	17.64	29.77
IRELAND	4.78	6.19	7.56	8.37	15.19	11.69	8.96
ITALY	20.59	21.55	23.24	21.45	24.05	13.07	20.66
PORTUGAL	19.47	22.03	20.61	20.60	24.00	12.68	19.90
SPAIN	8.46	8.86	8.16	7.50	9.21	6.73	8.15
Foreign banks' claims on banks debt/GDP							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
GREECE	6.23	7.02	10.04	12.17	10.33	3.55	8.23
IRELAND	103.93	120.21	140.62	100.51	92.71	51.09	101.51
ITALY	10.85	12.87	14.97	11.03	9.46	7.38	11.09
PORTUGAL	15.77	19.14	23.58	19.71	21.08	15.88	19.19
SPAIN	16.72	20.78	26.61	23.51	23.03	14.91	20.93
Foreign banks' claims on non-financial private sector debt/GDP							
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
GREECE	16.73	27.42	35.73	36.01	26.07	26.22	28.03
IRELAND	133.91	177.50	251.16	269.12	252.07	213.98	216.29
ITALY	11.60	20.67	28.28	23.07	24.97	22.83	21.90
PORTUGAL	32.12	38.35	46.84	46.22	49.83	45.57	43.15
SPAIN	17.38	25.38	33.61	29.83	30.52	25.09	26.97

Note: Reliance on foreign bank financing is measured by the consolidated claims on an immediate borrower basis of Bank for International Settlements (BIS) reporting banks on each sector (public, banks and non-financial corporations as a proportion of GDP). Data correspond to the end of each year.
Source: This table has been constructed from data collected from Table 9C of BIS Quarterly Review: June 2011 and the OECD.

Table 8. Claims by nationality of reporting banks as a proportion of total foreign claims.

GREECE	2005	2006	2007	2008	2009	2010	Average
Austrian banks	3.3	2.8	2.4	2.1	2.2	2.3	2.5
Belgian banks	8.7	5.6	5.7	3.8	2.0	1.3	4.5
Finnish banks	0.0	0.0	0.0	0.0	0.0	0.0	0.0
French banks	9.4	19.1	24.4	28.4	36.7	39.6	26.2
German banks	22.0	18.1	15.9	14.5	20.9	23.7	19.2
Irish banks	0.0	5.6	3.6	3.2	4.0	0.6	2.8
Italian banks	2.2	0.0	4.3	3.6	3.2	2.9	2.7
Dutch banks	11.3	8.8	7.9	4.9	5.7	3.5	7.0
Portuguese banks	1.9	2.3	2.5	2.4	4.6	7.2	3.5
Spanish banks	0.6	0.3	0.4	0.4	0.6	0.7	0.5
British banks	5.4	4.6	5.5	4.8	7.1	9.8	6.2
US banks	5.0	4.1	3.4	2.6	7.7	5.1	4.6
Others	30.3	28.7	24.0	29.3	5.4	3.3	20.2
IRELAND	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
Austrian banks	1.22	1.39	1.16	0.76	1.27	0.64	1.1
Belgian banks	8.82	10.52	8.42	6.75	5.68	5.62	7.6
Finnish banks	0.00	0.00	0.00	0.00	0.00	0.16	0.0
French banks	7.30	9.06	12.02	10.10	8.47	6.55	8.9
German banks	25.78	23.95	25.90	29.97	29.88	26.13	26.9
Greek banks	0.22	0.12	0.07	0.05	0.10	0.11	0.1
Italian banks	3.71	2.96	3.43	3.62	2.83	2.99	3.3
Dutch banks	9.92	7.49	5.69	5.25	4.58	3.70	6.1
Portuguese banks	0.52	0.75	0.40	0.56	0.76	1.14	0.7
Spanish banks	3.11	3.81	3.04	2.20	2.38	2.22	2.8
British banks	26.49	26.91	26.21	28.22	27.12	29.91	27.5
US banks	3.15	3.97	4.51	4.89	9.28	11.27	6.2
Others	9.77	9.07	9.15	7.63	7.67	9.57	8.8
PORTUGAL	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
Austrian banks	1.39	1.31	1.09	1.11	1.15	0.81	1.1
Belgian banks	5.14	6.65	4.77	5.28	2.33	1.75	4.3
Finnish banks	0.00	0.00	0.00	0.00	0.00	0.19	0.0
French banks	10.28	10.55	13.79	13.11	17.83	13.33	13.1
German banks	20.64	19.27	20.05	19.50	18.79	18.03	19.4
Greek banks	0.02	0.01	0.02	0.02	0.05	0.04	0.0
Irish banks	0.00	4.30	3.62	2.78	2.16	1.35	2.4
Italian banks	3.18	3.83	3.39	2.72	2.66	2.01	3.0
Dutch banks	7.45	6.66	7.39	6.07	5.61	3.24	6.1
Spanish banks	35.12	31.99	32.23	33.93	33.71	41.89	34.8
British banks	11.17	8.68	8.55	9.62	10.20	12.05	10.0
US banks	1.64	2.26	1.51	0.81	1.85	2.61	1.8
Others	3.98	4.50	3.60	5.05	3.66	2.70	3.9
SPAIN	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
Austrian banks	0.86	0.87	0.82	0.87	0.96	0.95	0.9
Belgian banks	4.22	4.52	4.44	4.82	2.46	3.06	3.9
Finnish banks	0.00	0.00	0.00	0.00	0.00	0.22	0.0
French banks	18.25	14.94	18.92	19.35	22.97	20.01	19.1
German banks	26.51	30.07	29.23	27.83	25.89	25.88	27.6
Greek banks	0.06	0.01	0.01	0.03	0.04	0.05	0.0
Irish banks	0.00	3.86	3.84	3.70	3.45	2.13	2.8

Italian banks	2.49	2.34	2.70	3.12	3.39	4.22	3.0
Dutch banks	16.87	13.95	13.36	13.69	13.02	10.94	13.6
Portugal banks	2.61	2.84	2.77	3.14	3.14	3.80	3.0
British banks	15.23	13.84	12.55	13.66	11.98	15.25	13.8
US banks	4.55	4.72	4.12	3.67	6.31	6.72	5.0
Others	8.35	8.02	7.25	6.12	6.37	6.78	7.1
ITALY	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**Average**
Austrian banks	2.64	2.19	2.04	1.61	2.23	2.58	2.2
Belgian banks	10.85	8.09	4.38	4.74	2.83	2.99	5.6
Finnish banks	0.00	0.00	0.00	0.00	0.00	0.08	0.0
French banks	18.94	27.45	37.66	42.79	44.44	45.53	36.1
German banks	25.26	20.10	19.41	18.91	16.60	18.82	19.9
Greek banks	0.15	0.07	0.02	0.03	0.06	0.07	0.1
Irish banks	0.00	5.20	3.94	4.25	3.99	1.53	3.2
Dutch banks	10.84	13.82	11.65	6.11	6.04	5.26	9.0
Portuguese banks	0.76	0.75	0.41	0.32	0.47	0.35	0.5
Spanish banks	4.44	2.99	2.82	4.44	4.13	3.62	3.7
British banks	9.22	7.02	7.09	6.83	6.71	7.70	7.4
US banks	5.78	3.25	2.79	2.33	4.66	4.26	3.8
Others	11.12	9.08	7.78	7.65	7.84	7.21	8.4

Note: Table 8 displays the consolidated claims on an immediate borrower basis of Bank for International Settlements (BIS) by nationality of reporting banks as a proportion of total foreign claims on each country. Data correspond to the end of each year.
Source: This table has been constructed from data collected from Table 9D of BIS Quarterly Review: June 2011.

Table 9: Probit models

Greece → Ireland

	Coefficient	z-Statistic
GRIEBAN	19.4772	2.5471
GRGOVDEB	-0.0607	-2.2599
GROGR	-0.1322	-2.1527
DEFIE	0.1165	2.0749
IEBAN	-0.0312	-2.2786
IEPRI	0.0196	2.1867
GRBANDEB	0.1266	2.2458
McFadden R-squared	0.7386	

Ireland → Greece

	Coefficient	z-Statistic
Constant	-2.8012	-2.0634
IEGRBAN	91.6240	2.9967
IEPUB	1.2065	2.9655
DEFIE	0.0926	2.2747
McFadden R-squared	0.7198	

Greece → Italy

	Coefficient	z-Statistic
Constant	165.0794	2.1985
GRITBAN	3.5560	2.2579
INFGR	4.58□0	3.6□72
GROGR	-6.3392	-3.4648
RATGR	1.2271	-2.0386
GRGOVDEB	0.8118	-2.1946
McFadden R-squared	0.8058	

Italy → Greece

	Coefficient	z-Statistic
Constant	-177.6220	-2.7693
ITGRBAN	3.8020	2.5559
DEFIT	0.6852	2.4742
ITBANDEB	0.0458	2.5783
LEAIT	-0.428□	-2.6075
RATGRE	4.0481	3.8010
ITPUB	2.7413	2.6193
ITHOUDEB	6.1249	2.9754
McFadden R-squared	0.7341	

Greece → Portugal

	Coefficient	z-Statistic
Contant	-3.1133	-2.1357
GRPTBAN	53.5999	2.5940
INFGR	2.3869	2.1412
UGR	7.7531	2.7749
GRGOVDEB	0.8771	3.4462
VARRATPT	5.8638	3.9751
GRNFIDEB	1.1808	3.9503
GRPUB	1.6704	2.6380
GRPRI	0.8294	3.4910
McFadden R-squared	0.8474	

Portugal → Greece

	Coefficient	z-Statistic
Constant	-96.3741	-4.2545
PTGRBAN	5.9734	3.3352
INFPT	3.2890	3.9156
UPT	8.1793	4.2537
DEFPT	0.3027	2.3217
PTNFIDEB	1.3158	2.7293
PTPUB	0.5964	2.3633
PTBANDEB	0.9296	2.6373
McFadden R-squared	0.7386	

Greece → Spain

	Coefficient	z-Statistic
Constant	-6.2095	-1.4073
GRSPBAN	7.2864	2.4876
UGR	4.1365	5.5873
GRGOVDEB	0.3101	4.3304
DEFSP	0.2693	2.5897
McFadden R-squared	0.8125	

Spain → Greece

	Coefficient	z-Statistic
Constant	-99.4167	-4.1675
SPGRBAN	33.1269	3.9718
SPBANDEB	0.3791	2.5198
SPANFIDEB	0.1302	2.4135
RATGR	1.3577	2.6305
RATSP	5.6458	2.6104
CACSP	1.1596	2.4870
SPPUB	10.1523	3.2375
McFadden R-squared	0.7093	

Spain → Portugal

	Coefficient	z-Statistic
Constant	-40.6506	-2.8468
SPPTBAN	6.9212	2.1449
SPNFIDEB	2.6210	3.2914
UPOR	3.1901	2.7406
McFadden R-squared	0.6611	

Portugal → Spain

	Coefficient	z-Statistic
PTSPBAN	12.1144	2.5430
DEFPT	0.3725	2.1648
GROPT	-13.9959	-2.6106
INFPT	-6.6052	-2.3755
VARRATPT	0.2782	2.2489
GROSP	12.8877	2.6820
SPGOVDEB	-1.1445	-2.5831
McFadden R-squared	0.8088	

Spain → Italy

	Coefficient	z-Statistic
Constant	18.1615	2.1399
SPITBAN	4.7558	2.3862
DEFSP	0.2929	2.1964
LEASP	-3.4998	-2.8219
SPGOVDEB	1.9947	2.4978
CACSP	-2.5224	-2.8436
LEAIT	2.8028	2.2771
ITPUB	3.1219	2.1977
RATIT	2.4639	2.2641
McFadden R-squared	0.6269	

Italy → Spain

	Coefficient	z-Statistic
Constant	-27.3744	-2.0622
ITSPBAN	2.8219	2.0290
DEFIT	0.5317	2.1852
ITBANDEB	0.3654	2.2033
LEAIT	-0.2687	2.8245
RATSP	10.2186	3.2582
ITGOVDEB	0.1419	2.5303
UIT	6.9282	2.8391
McFadden R-squared	0.7466	

Italy → Ireland

	Coefficient	z-Statistic
Constant	69.3280	3.1186
ITIEBAN	6.2755	3.4121
DEFIT	0.0083	2.0548
ITBANDEB	0.3962	3.5773
LEAIT	-0.9472	4.1862
RATIE	5.5569	4.6048
ITHOUDEB	1.4920	2.8739
ITGOVDEB	0.5991	3.5876
McFadden R-squared	0.6557	

Ireland → Italy

	Coefficient	z-Statistic
Constant	-34.7139	-3.7590
IEITBAN	0.0110	2.0619
IEPUB	4.9328	3.8503
DEFIE	0.3727	3.0778
INFIE	1.6927	3.5820
McFadden R-squared	0.8173	

Portugal → Ireland

	Coefficient	z-Statistic
Constant	5.8309	2.3371
PTIEBAN	53.9490	2.5308
DEFPT	1.3717	3.1335
GROPT	-1.3577	-2.6080
INFPT	1.8180	2.0768
RATPT	0.8849	2.4420
GROIE	-0.2628	-2.4346
IEGOVDEB	0.0779	2.2206
McFadden R-squared	0.7313	

Ireland → Portugal

	Coefficient	z-Statistic
Constant	-103.6540	-4.7475
IEPTBAN	1.0914	2.9016
IEPUB	2.1862	2.8636
DEFIE	0.7100	3.1511
LEAIE	-2.9091	-4.4582
IEBAN	0.2298	2.4472
IEGOVDEB	1.9663	2.9986
UPT	5.5731	2.3205
CACPT	-6.9992	-4.8327
McFadden R-squared	0.8195	

Spain → Ireland

	Coefficient	z-Statistic
Constant	98.8600	2.8023
SPIEBAN	1.2292	2.1407
DEFSP	0.0476	2.8906
LEASP	1.2608	3.1738
SPBAN	2.1513	2.9228
SPGOVDEB	2.2618	3.0030
CACSP	-0.6272	-2.1229
GROIE	-0.7570	-3.7996
SPBANDEB	0.3240	2.7109
McFadden R-squared	0.6750	

Ireland → Spain

	Coefficient	z-Statistic
Constant	-4.4028	-2.6272
IESPBAN	0.3133	2.6764
IEPUB	1.7950	3.1077
DEFIE	0.4638	3.2044
IEBAN	0.0749	3.1281
IEGOVDEB	1.0637	3.1027
USP	2.2242	2.9601
McFadden R-squared	0.7045	

Portugal → Italy

	Coefficient	z-Statistic
Constant	-59.3698	-4.0692
PTITBAN	4.8112	2.4425
DEFPT	0.4549	2.2626
UPT	2.5365	2.1736
RATPT	7.2804	3.9456
UIT	2.5939	3.0013
PTPUB	1.8024	4.2752
RATIT	1.0716	2.6486
PTGOVDEB	0.7401	3.3067
McFadden R-squared	0.5595	

Italy → Portugal

	Coefficient	z-Statistic
Constant	28.0712	2.0045
ITPTBAN	6.8975	3.3487
DEFIT	0.6021	2.5329
UIT	3.5979	2.8359
UPT	5.7698	2.7683
ITHOUDEB	2.7336	3.2757
RATIT	1.3327	2.1908
ITGOVDEB	1.3677	3.2470
McFadden R-squared	0.7383	

Note:

CACXX = Current-account-balance-to-GDP of country XX

LEAXX = Leading indicator index rate of growth of country XX

GROXX = GDP (constant prices) rate of growth of country XX

UXX = Unemployment rate of country XX

INFXX = Inflation rate of country XX

RATXX = Credit rating scale of country XX.

DEFXX = Government deficit-to-GDP of country XX.

XXGOVDEB = Government debt-to-GDP of country XX.

XXBANDEB = Bank debt-to-GDP of country XX

XXNFIDEB = Non-financial corporations debt-to-GDP of country XX

XXHOUDEB = Households debt-to-GDP of country XX

XXBAN = Foreign bank claims on banks debt-to-GDP of country XX

XXPUB = Foreign bank claims on government debt-to-GDP of country XX

XXPRI = Foreign bank claims on non-financial private debt-to-GDP of country XX

XXYYBAN = Percentage of country XX's foreign claims held by country YY's banks

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