

How did the Financial Crisis affected the Real Interest Rates in Europe?

Abstract

We investigate the effects of the financial crisis on the stationarity of real interest rates for a group of Euro area countries. We use a new unit root test developed by Pesaran *et al.* (2013) that allows for multiple unobserved factors in a panel set up. In this multifactor framework, we make use of a number of additional variables such as the stock price volatility and monetary policy expectations that are assumed to share common factors with the real interest rate. Based on recursive Pesaran *et al.* (2013) test statistics, our results suggest that while short-term and long-term real interest rates were stationary before the financial crisis, they became non-stationary after around 2008. Robustness analysis shows that the results are not sensitive to the use of *ex-post* real interest rates vs. *ex-ante* real interest rates.

JEL codes: E43, C23

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1. Introduction

The effects of the 2007-2009 financial crisis has been a popular research question. The post-crisis literature evolved in multiple paths. One strand focused on the effects of the crisis in financial markets. These studies tried to assess the liquidity and credit risks associated with the financial crisis in advanced economies. A majority of the researchers attributed the increase in the Libor-OIS spread, which has been viewed as the barometer of financial stress, to the elevated levels of market and/or liquidity risk (see e.g. Taylor and Williams, 2009, McAndrews et al., 2008, Eisenschmidt and Tapking, 2009, Wu, 2008, Carpenter *et al.*, 2016). A second branch focused on the macroeconomic effects of the crisis and particularly the effects of policy measures to offset the slowdown in economic growth (see e.g., Lenza et al., 2010, and Fahr et al., 2011, Gambacorta and Marques-Ibanez, 2011, Carpenter, Demiralp and Eisenschmidt, 2014). These studies documented varying effects of the policies on the real economy. Yet another branch of literature investigated the structural changes imposed by the crisis. Didier *et al.* (2012) documented a structural break in the way emerging market economies responded to the global shock, where they studied the financial as well as the real side of these economies. Likewise, Carpenter, Demiralp and Senyuz (2014) identified three distinct money market stress cycles during the 2007-2009 period.

In this paper, we focus on the effects of the financial crisis on real interest rates for a group of Euro area countries. We hypothesize that the structural changes imposed by the financial crisis and documented in the earlier literature may have affected the stationarity of real interest rates. For that purpose, we exploit the traditional framework of the Fisher hypothesis. The Fisher hypothesis argues that changes in inflation expectations have one-to-one impact on nominal interest rates such that the real interest rate remains constant (Fisher, 1930). An

implication of the Fisher hypothesis is that the real interest rate, which is the difference between the nominal interest rate and expected inflation rate, should be stationary. The stationarity of the real interest rate is also implied by consumption based intertemporal models of asset prices (see e.g. Lucas, 1978) or the canonical neoclassical growth models with explicitly optimizing infinitely lived agents (see Romer, 1996, chapter 2).

While the stationarity of the real interest rates lies at the core of classical macroeconomic theory, empirical tests of stationarity predominantly rejected the stationarity of real interest rates (see e.g. Rose, 1988, Mishkin, 1995, Evans and Lewis, 1995, Crowder and Hoffman, 1996, Lanne, 2001, Atkins and Coe, 2002).¹ The presence of a unit root in real interest rates suggests market inefficiencies, where market frictions such as imperfect competition in the banking industry, sticky prices, or information costs prevent the nominal interest rates from adjusting one-to-one with inflation, contradicting the asset pricing model suggested by Fisher (1930).

One of the early evidences in favor of stationary short-term real interest rates is due to Fama (1975) who illustrated that real Treasury bill rates up to six months are stationary for the period from 1953 to 1971. However, Fama's work has been criticized for not being representative of the twentieth century (see Rose, 1998, Shiller, 1979, Mishkin, 1981). In contrast to this earlier literature, in a recent study, Lai (2008) found evidence in favor of the stationarity of real interest rates for a group of industrial as well as developing countries, after allowing for a structural break.

Most of the earlier studies performed unit root tests of real interest rates for each country individually. Different from the earlier literature, in this paper we consider unit root tests for a group of Euro area countries with lax capital controls and common monetary policy. These

¹ For a recent review of the literature, see Neely and Rapach (2008).

countries are: Austria, Belgium, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain as well as Denmark.² We exclude those countries that joined the European Union after the formation of the European Central Bank (ECB), which is the starting date of our sample. This exclusion restriction allows us to have a longer panel dataset. Specifically, we adopt a panel framework and utilize a flexible and intuitive test proposed by Pesaran et al. (2013). This test allows for the possibility that individual real interest rates are interdependent due to common factors that are believed to drive the co-movements among these rates. Interdependence (or cross-sectional dependence) is an issue that has attracted considerable attention among researchers in recent years (Sarafidis and Wansbeek, 2012). In Pesaran (2007), cross-sectional dependence was characterized by a single common factor. In Pesaran *et al.* (2013), this idea is extended and cross-sectional dependence is modeled by multiple common factors instead. We believe that a multiple common factor framework is more appropriate in an analysis that investigates the behavior of real interest rates where there could be several drivers for the common movements of these rates. As we illustrate, such drivers for our sample are the stock price volatility and monetary policy expectations. Further advantages of the panel set up, compared to individual tests, include the use of more information regarding the common dynamics within the panel, more variability in the data, and efficiency in estimation.

Our main results are summarized as follows: Following a recursive approach to Pesaran *et al.* (2013), we find that while short-term as well as long-term real interest rates in the Euro area were stationary before the financial crisis, they became non-stationary during the period after the crisis. As a robustness check, we compare the sensitivity of the results to the use of ex-

² Even though Denmark does not use the Euro, its national currency, the Krone, is pegged to the Euro. Hence, the National Bank of Denmark closely tracks the changes made by the European Central Bank. Ideally, we would have liked to use data on Finland. However, the Finnish interest rate data is not available from Bloomberg. We were able to find data released by the OECD but only at the quarterly frequency.

post real interest rates vs. *ex-ante* real interest rates. Our findings suggest that the results are generally insensitive to the use of *ex-post* real interest rates.

The argument of common real interest rate dynamics is primarily driven by the fact that most countries in our dataset are members of the Euro system that share a common monetary policy. The argument is further supported by the existence of arbitrage opportunities that are exploited in the absence of restrictions on capital flows. Most of the countries that comprise our sample are ranked as the “most financially open” countries based on Chinn-Ito financial openness index (Chinn and Ito, 2008). Note that this is an assumption that we test formally and illustrate that there is strong evidence of common cross sectional dynamics in our sample.

Testing for the stationarity of real interest rates is essential from a macroeconomic perspective. Stationarity of real returns is important for the assessment of financial market stability. The real interest rate is the main determinant of investment and savings decisions and hence it plays an essential role in the determination of asset prices over time. In that respect, the stationarity of interest rates has direct implications on the viability of consumption-based asset pricing models (see e.g. Hansen and Singleton, 1983). Our goal in this paper is to provide a proper assessment of the stationarity of real rates, after incorporating common dynamics across countries. A priori, we believe that the financial crisis would tend to disrupt the stationarity features of real interest rates due to the higher economic uncertainty and thus higher variability in the real interest rates.³ For example, the three panels in Figure 1 plot the real interest rate series used in the analysis for the 3-month, 1-year, and 5-year interest rates respectively. A casual observation allows one to detect a general increase in the mean and variance of all maturities during the crisis period.

³ For more information on the zero lower bound, see e.g. Chung et al. (2012).

A closely related paper is by Camarero *et al.* (2010) who apply panel stationarity tests to the real interest rate differentials across OECD countries. Another related study is Costantini and Lupi (2007) who implement panel unit root tests to inflation and 3-month interest rates separately. In both papers, the authors bootstrap the test to allow for cross-sectional dependence, and show that the data are rather stationary subject to infrequent shifts in their mean.

The idea of investigating the stationarity of real interest rate differentials is also explored by Holmes (2002) for major European Union countries, although with a different procedure. The author applies the Im *et al.* (2003) methodology which is also designed for a panel but assumes no cross-sectional dependence. Holmes (2002) finds evidence of stationarity mainly during the 1986-1990 and 1993-1998 periods. However, since we find significant cross-sectional dependence in the data, this methodology is not appropriate for our dataset.

The remainder of the paper is organized as follows. In the next section, we briefly discuss the Fisher hypothesis and the data used in the analysis. Section 3 goes over the methodology of panel unit root tests, and illustrates the empirical results. The fourth section concludes. Finally, in the Appendix we check the sensitivity of the results to the use of *ex-post* real interest rates vs. *ex-ante* real interest rates.

2. Empirical Framework

2.1 Real Interest Rates

According to the Fisher equation, the one-period nominal interest rate at time t is determined by:

$$i_t = r_t + \pi_t^e \quad (1)$$

where i_t is the nominal interest rate, r_t is the *ex-ante* real interest rate, and π_t^e is the expected inflation rate. The idea is that if changes in inflation expectations do not have any permanent

effect on the real interest rate, they have a one-to-one impact on the nominal interest rate. This implies that the real interest rate is stationary.

Solving for the real interest rate:

$$r_t = i_t - \pi_t^e \quad (2)$$

We use equation (2) to construct real interest rate series in our analysis.

2.2 The Data

Our dataset includes short-term (3-month) and long-term (1-year and 5-year) nominal interest rates and inflation rates of the ten European countries at the monthly frequency. The data on interest rates is obtained from *Bloomberg* while the inflation rate data, captured by the consumer price index (CPI) is from the Federal Reserve Economic Data (FRED) database. Ideally, the computation of the real interest rate requires the expected inflation rate series. Nevertheless, data on inflation expectations is rather limited, which forces us to use the realized inflation rates from the CPI data as a proxy for inflation expectations. To the extent that the forecast error, that is, the difference between the expected and realized inflation rates, is stationary, using the realized inflation rate instead of the expected rate should not affect the dynamic properties of the unit root tests (Lai, 2008). As a robustness check, we were able to obtain data on inflation expectations for a much limited subset of the five of the Euro Area countries in our sample from Consensus Economics.⁴ For that small sample, the forecast error between the expected and the realized interest rates is found to be stationary based on Pesaran *et al.* (2013) test (not shown), providing support for the use of the realized inflation rate as a substitute for inflation expectations. Furthermore, the reliability of the data on inflation

⁴ *Consensus Economics* provides survey forecasts for the following Euro Area countries in our sample: Germany, France, Italy, Netherlands, and Spain. More information can be found at: http://www.consensuseconomics.com/what_are_consensus_forecasts.htm

expectations is problematic, because it has to be based on either a survey or an econometric forecast. Hence, using *ex-post* real interest rate with the realized inflation rate remains to be the only other option. As for our control variables (explained later in the text), we use the stock price volatility (VSTOXX), and the 12-month Overnight Index Swap (OIS) rate (Figure 2).

3. Empirical Analysis

In testing for the stationarity of the real interest rate, we first utilize the Fisher hypothesis and compute the real interest rate as the difference between the nominal interest rate and the inflation rate. We then input this real rate in our analysis. The sample period starts in January 1999 with the authorization of the European Central Bank for the implementation of single monetary policy for the Euro Area. The sample ends in July 2012.

3.1 Methodology

This section briefly presents the econometric methodology. We utilize the cross-sectionally augmented Dickey-Fuller (DF) regression of Pesaran *et al.* (2013). In this set up, we need to add $m^0 - 1$ exogenous regressors that are likely to share common factors with real interest rates, where m^0 is the true number of common factors. The test regression of interest is given by:

$$\Delta y_{it} = \mu_i + b_i y_{it-1} + \phi_i \bar{y}_{t-1} + c_{1i} \bar{x}_{1t-1} + \dots + c_{ki} \bar{x}_{kt-1} + \psi_i \Delta \bar{y}_t + h_{1i} \Delta \bar{x}_{1t} + \dots + h_{ki} \Delta \bar{x}_{kt} + e_{it} \quad (3)$$

for $i = 1, \dots, N; t = 1, \dots, T$

where y_{it} is the real interest rate in country i in month t and define a $k \times 1$ vector of additional regressors, $x_{it} = (x_{1it}, \dots, x_{kit})'$, which are assumed to share common factors with the real interest

rate series. Note that Eq. (4) is a standard DF regression augmented with the lagged level and the first difference of the cross-sectional mean of the individual real interest rates ($\bar{y}_t = N^{-1} \sum_{j=1}^N y_{jt}$) as well as of the individual additional regressors ($\bar{x}_{1t} = N^{-1} \sum_{j=1}^N x_{1jt}$, ..., $\bar{x}_{kt} = N^{-1} \sum_{j=1}^N x_{kjt}$). The additional regressors can help us recover useful information about the common factors. In our application, x_{it} includes the stock price volatility index ($VSTOXX_t$), to capture the overall uncertainty in the Euro area, and the 12-month OIS rate ($OIS12_t$), to capture long-term monetary policy expectations (see Figure 2).⁵ Before settling with these regressors, we also experimented with other regressors similar to those in the application in Pesaran *et al.* (2013), such as oil prices, stock prices or exchange rates but we found these regressors to be less useful.

In this set up, cross-sectional means and time series data proxy for the common factors. Interpreting the common factors as common interest rate dynamics, the above specification implies that the real interest rate in any country i consists of common factors plus an idiosyncratic movement. Furthermore, this specification is general enough to allow for serial correlation in the residuals, in the common factors, or both. We test the null hypothesis

⁵ Note that VSTOXX is a volatility index that is based on EURO STOXX 50 real time options prices. It is designed to reflect the market expectations of near-term to long-term volatility by measuring the square root of the implied variance across all options of a given time to expiration. Meanwhile, OIS are over-the-counter traded derivatives in which the parties exchange at maturity the difference in interest between what would accrue over the life of the contract under the fixed rate assumption and what would accrue from repeatedly rolling over an investment in the overnight market. The OIS rate can be viewed as a measure of market participants' expected policy rate over the relevant term (see e.g. Taylor and Williams, 2009) as the floating leg is tied to a published index of a daily overnight rate reference, like the EONIA (Euro OverNight Index Average) rate. In fact, the OIS rate equals the average of the overnight interest rates expected until maturity and as such is indeed a measure of expected monetary policy rate over the relevant maturities.

$H_0: b_i = 0, \forall i$ (non-stationary process) against the alternative $H_1: b_i < 0$, for at least some i (partially stationary process).⁶

The above cross-sectionally augmented DF regression can be further enhanced with lagged changes $\Delta y_{it-s}, \Delta \bar{y}_{t-s}, \Delta x_{lit-s}, \Delta \bar{x}_{lt-s}, \dots, \Delta x_{kit-s}, \Delta \bar{x}_{kt-s} (s = 1, \dots, p)$ to account for possible autocorrelation in the errors. This double augmented DF regression is referred to as the CADF regression. We obtain the CADF statistics for each of the real interest rate series in the panel. Then, we calculate their simple average, thus obtaining the CIPS (Cross-sectionally Augmented IPS) statistic.⁷ This test is an extension of the IPS test proposed by Im *et al.* (2003) which is also designed for a panel but assumes no cross sectional dependence.

3.2 Full Sample Analysis

We first apply the Pesaran *et al.* (2013)'s test for the full sample. Before considering the CIPS test, we tested whether the cross-sectional dependence is statistically significant. To that end, we estimated individual Augmented Dickey-Fuller (ADF) regressions, of order 4 ($\hat{p} = [4(T/100)^{1/4}]$) without cross-sectional augmentations, and calculated pair-wise cross-sectional correlations of the residuals from these regressions, $\hat{\rho}_{ij}$. Then, we calculated the

average across all pairs, $\bar{\rho} = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}$ and the associated cross-sectional

dependence (CD) statistic of Pesaran (2004), $CD = \left[\frac{TN(N-1)}{2} \right]^{1/2} \bar{\rho}$. Pesaran (2015) establishes

that the implicit null hypothesis of the CD test is that of weak-cross sectional dependence while

⁶ Technically, it is assumed that the fraction of the individual processes that are stationary is non-zero and tends to a fixed value $0 < \delta \leq 1$ as $N \rightarrow \infty$.

⁷ Pesaran *et al.* (2013) study the finite-sample properties of the CIPS test by Monte Carlo simulations. They find the test does not generally seem to suffer from any size distortion.

the alternative hypothesis is strong cross sectional dependence. The author shows that the test has a standard normal distribution when the errors are symmetrically distributed.

Table 1 illustrates the CD test results for the full sample. As seen, there is strong evidence against the null of weak cross-sectional dependence with the longer-term interest rates being more interdependent. This verifies the use of the Pesaran et al. (2013)'s unit root test where the average cross-section correlation, $\bar{\hat{\rho}}$, is around 30 percent for short-term (3-month) interest rates, and somewhat higher for long-term (1-year and 5-year) interest rates. This finding supports the argument of common real interest rate dynamics for our sample of ten countries. Therefore, we proceed with the application of the Pesaran et al. (2013)'s test with the results displayed in Table 2. Notice that when applied to the full sample 1999-2012 these techniques fail to reject the unit root hypothesis for the real interest rates.

Next, we test for a structural break in the real interest rates dynamics. This step is important because if we detect a structural break in real interest rates, then we should incorporate this information in our stationarity analysis. The structural break tests are carried out in a univariate set up. Table 3 reports the Andrews SupWald test of a regression of the interest rate on a constant. The results show evidence of a structural break in the unconditional mean during the 2008-2011 period. We also test for a structural break in the squared of the interest rate and find similar break dates (Table 4). The suggestion of a structural break in the post-crisis period is consistent with our expectations that the global financial crisis or the subsequent Euro area sovereign debt crisis may have disrupted the dynamics of the data (see next section). While it is impossible to identify whether the underlying cause of structural break is due to the lagged

spillovers of the global financial crisis or the Euro Area sovereign debt crisis, the dates are consistent with both events.

3.3 Recursive Analysis

The evidence of a structural break in the previous section prompts us to run the Pesaran *et al.* (2013) test recursively to accommodate a possible break in real interest rates. Historically, recursive methods have been important tools in the unit-root literature to address the issue of structural breaks (Banerjee *et al.*, 1992). We aim to be as agnostic as possible about selecting the break date and therefore we carry out a systematic search. Our procedure is as follows: We compute recursive Pesaran *et al.* (2013) test statistics using sub-samples $t = 1, \dots, R$, for $R = 2007m1, \dots, 2012m7$. We then consider the minimal value of the test statistic and reject the null hypothesis of a panel unit root if this minimal value is small enough. The plot of the CIPS test statistics with the corresponding 5% critical value are provided in Figure 3. As seen, the CIPS statistic is minimized in 2007m2 for all three interest rates. Therefore, this date provides the strongest evidence against the null of a unit root in the panel. More importantly, the recursive analysis shows that up until around 2007 the panel appears stationary, while including the post-2007 sample the real interest rates become nonstationary. In sum, once we accommodate a structural break and cross-sectional dependence our results are supportive of the stationarity hypothesis prior to the crisis.⁸

⁸ Following the recommendation of a referee, we also included Greece in our dataset. The recursive CIPS test analysis was implemented for a shorter sample starting in 2001m1. Figure 4 reveals that the results are not very robust to the inclusion of Greece. Given the chronic deep recession in this country, the Greek interest rate ought to be considered as an outlier.

Altogether, our findings suggest that interest rates in the Euro area seem stationary prior to the crisis period consistent with the Fisher hypothesis or the consumption based intertemporal models of asset prices. The post-crisis period changes this picture. The appendix provides a robustness analysis comparing the sensitivity of the results to the use of *ex-post* real interest rates vs. *ex-ante* real interest rates. Our findings suggest that the results are generally insensitive to the use of *ex-post* real interest rates.

4. Conclusions

In this paper, we tackled a rather old question with new methodology. Although many macroeconomic theories are based on the assumption of stationary real interest rates, empirical evidence supporting the theory has been rather scarce. We have shown that for the group of European countries analyzed in this paper, incorporating additional information such as common monetary policy expectations and stock market volatility, makes a crucial difference in yielding the stationarity result of real interest rates. By using proper technology, we have provided strong evidence in favor of the Fisher hypothesis or consumption based intertemporal models of asset prices both in the short run and the long-run. On the other hand, the interest rates become non-stationary during the period of financial crisis, possibly due to the increased economic uncertainty. The presence of a unit root in real interest rates for the post-crisis period violates the framework that is laid out by consumption based asset pricing models which require the assumption of stationarity for real interest rates and consumption growth. As noted in Rose (1988), non-stationarity of the real interest rate also has direct implications for the volatility of returns in financial markets as well as investment and savings decisions. In terms of the political implications, our results provide evidence that despite the excessive measures adopted by central

banks during the crisis period, the consequent uncertainty was imperfectly controlled and the nonstationarity of real interest rates could not be avoided. As indicated earlier, stationarity of real interest rates is crucial for savings and investment decisions and the post-crisis recession faced by the Euro area can be linked to this finding. In that respect, our results suggest that the policy measures adopted by the ECB were insufficient in stabilizing interest rates.

Table 1: Tests for cross-sectional dependence of *ex post* real interest rates

3m rate	CD	25.81***
	$\bar{\hat{\rho}}$	0.301
1 y rate	CD	29.35***
	$\bar{\hat{\rho}}$	0.343
5 y rate	CD	34.68***
	$\bar{\hat{\rho}}$	0.405

Notes: CD is the cross-sectional dependence (CD) statistic of Pesaran (2004, 2015), which follows the standard normal distribution when the errors are symmetrically distributed. $\bar{\hat{\rho}}$ is the average of the correlation coefficients across all $(10 \times 9) / 2 = 45$ pairs. The test is applied over full-sample period 1999m1-2012m7. *** indicates significance at 1 percent level.

Table 2: CIPS test statistics of *ex post* real interest rates

	CIPS
3m rate	-2.337
1 y rate	-1.978
5 y rate	-1.248

Notes: We use three common factors, $m^0 = 3$, to account for cross-sectional dependence. The variables in $\bar{x}_t = \{VSTOXX_t, OIS12_t\}$ are the additional regressors used for cross section augmentation along with $\bar{y}_t$. $VSTOXX_t$ is the volatility index, while $OIS12_t$ is the 12-month OIS rate. Lag order is selected as $\hat{p} = [4(T/100)^{1/4}] = 4$. A constant term is included in the test regression. The test is applied over the full-sample period 1999m1-2012m7.

Table 3: Structural breaks in *ex post* real interest rates

Country	Break dates (3m rate)	Break dates (1y rate)	Break dates (5y rate)
Austria	2010m3	2010m3	2010m3
Belgium	2010m3	2010m3	2010m3
Portugal	2011m3	2011m3	2011m3
Germany	2009m12	2009m12	2010m5
Denmark	2010m1	2009m12	2010m4
Spain	2011m4	2011m4	2008m12
France	2009m12	2009m12	2009m12
Ireland	2008m12	2009m1	2009m1
Italy	2008m10	2008m10	2008m10
Netherlands	2009m1	2009m1	2010m7

Notes: Andrews' Supremum Wald test.

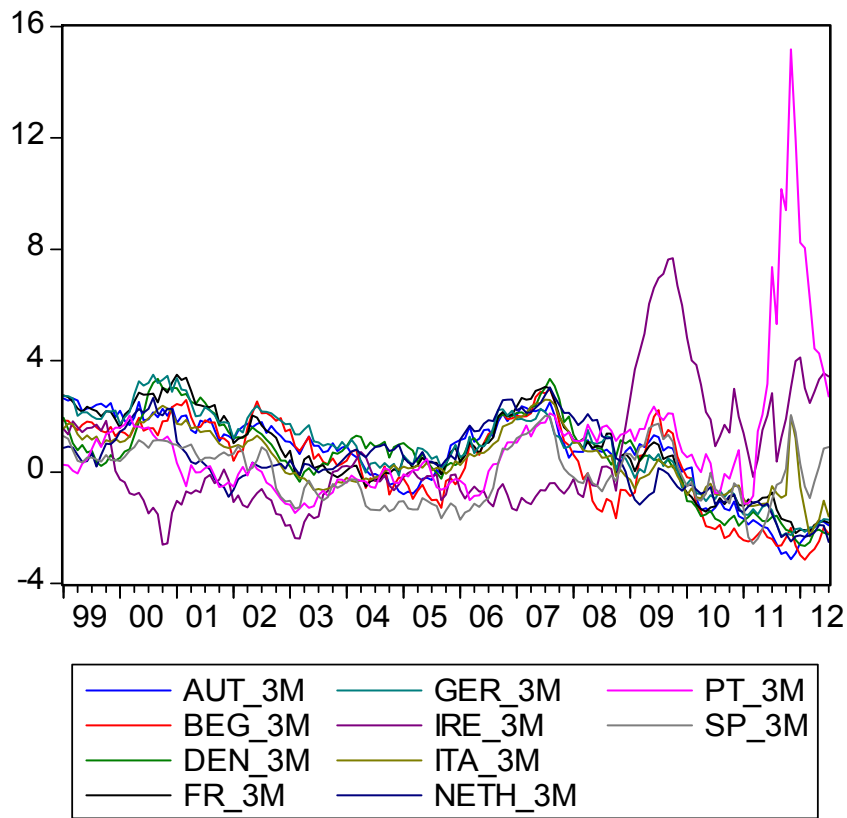
Table 4: Structural breaks in squared *ex post* real interest rates

Country	Break dates (3m rate)	Break dates (1y rate)	Break dates (5y rate)
Austria	2010m3	2010m3	2010m3
Belgium	2010m9	2010m3	2010m3
Portugal	2011m3	2011m3	2011m3
Germany	2009m12	2009m12	2010m5
Denmark	2010m1	2009m12	2007m11
Spain	2011m4	2011m4	2008m12
France	2009m12	2009m12	2009m12
Ireland	2009m2	2009m3	2009m2
Italy	2008m10	2008m10	2008m10
Netherlands	2006m2	2006m2	2010m7

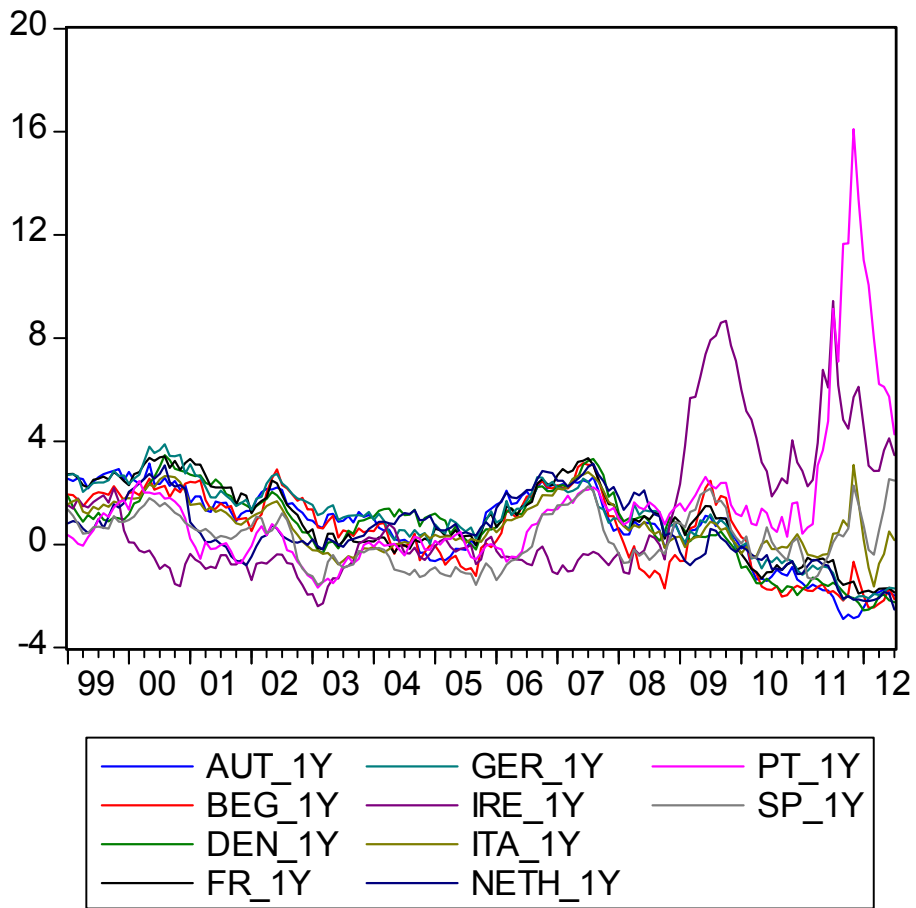
Notes: Andrews' Supremum Wald test.

Figure 1: Real Interest Rates

a) 3-month interest rates



b) 1-year interest rates



c) 5-year interest rates

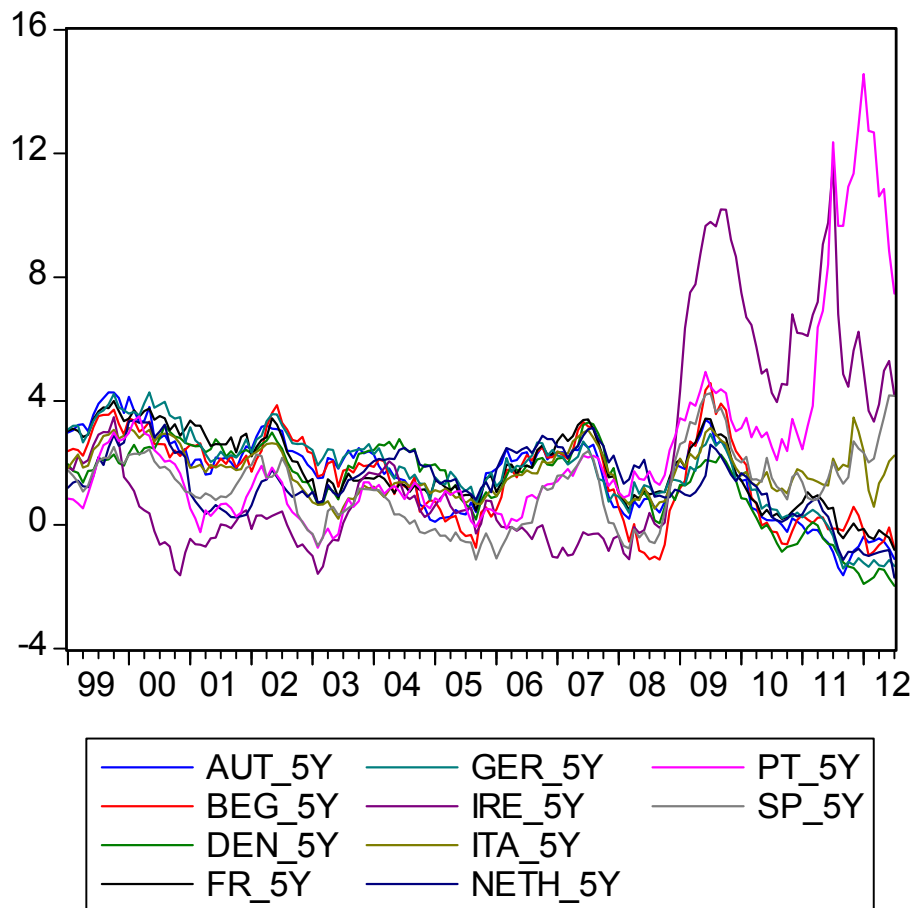


Figure 2: Stock market volatility (VSTOXX) and 12-month OIS rate.

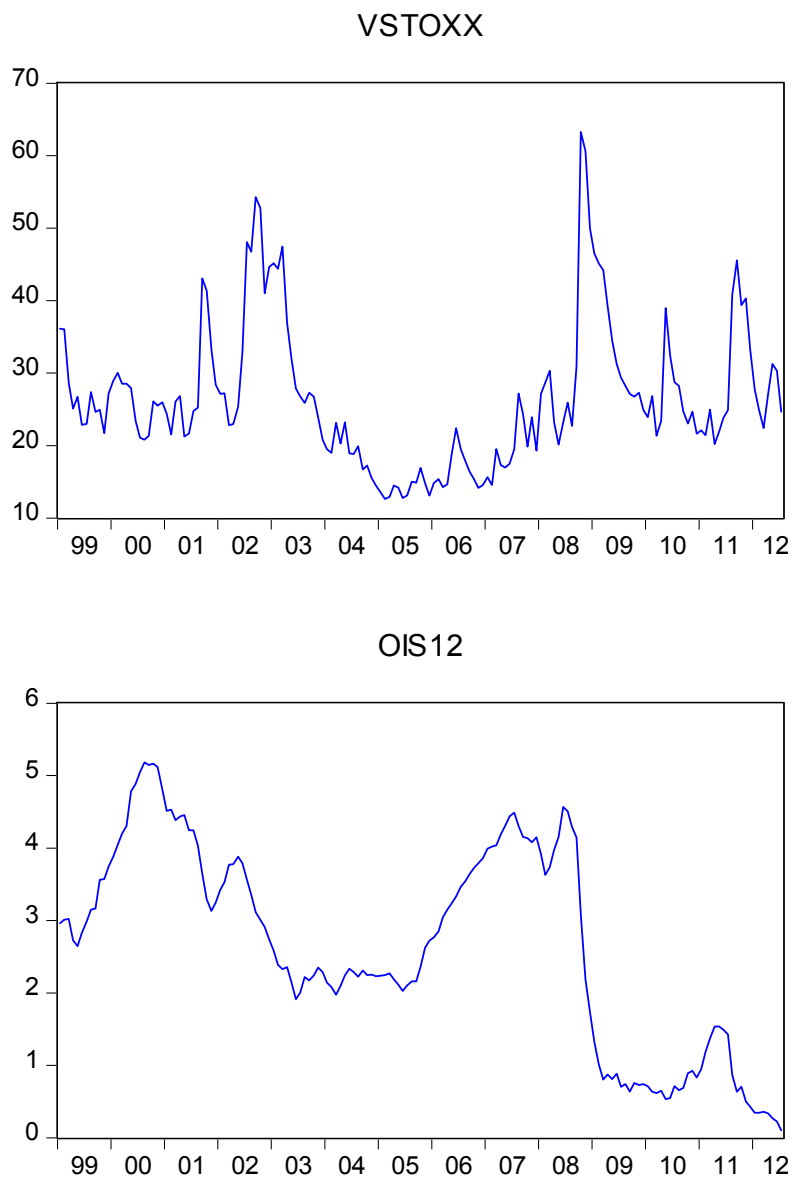
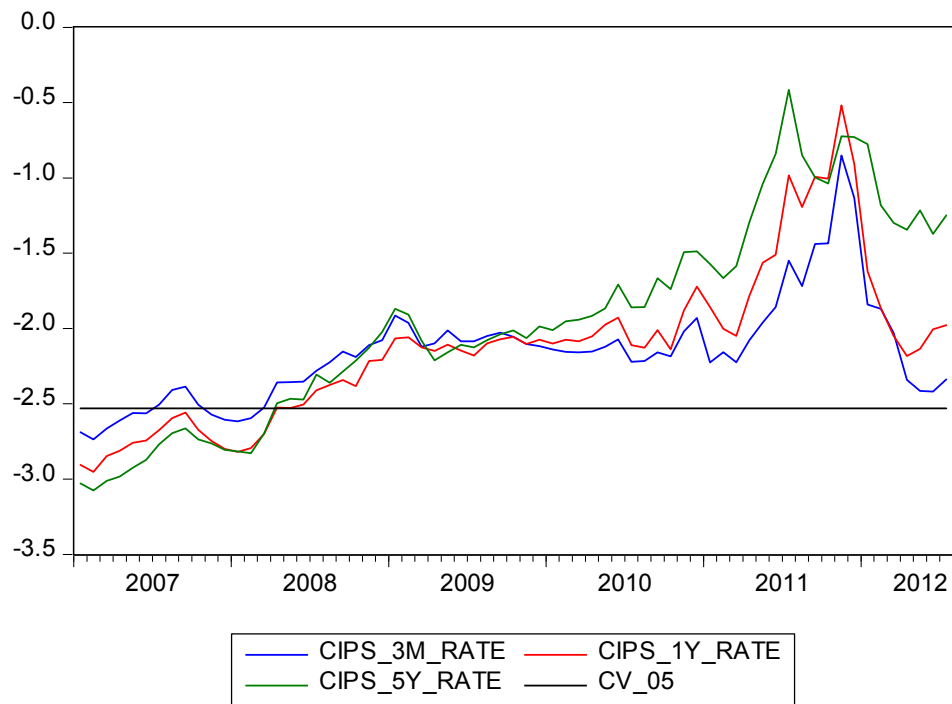


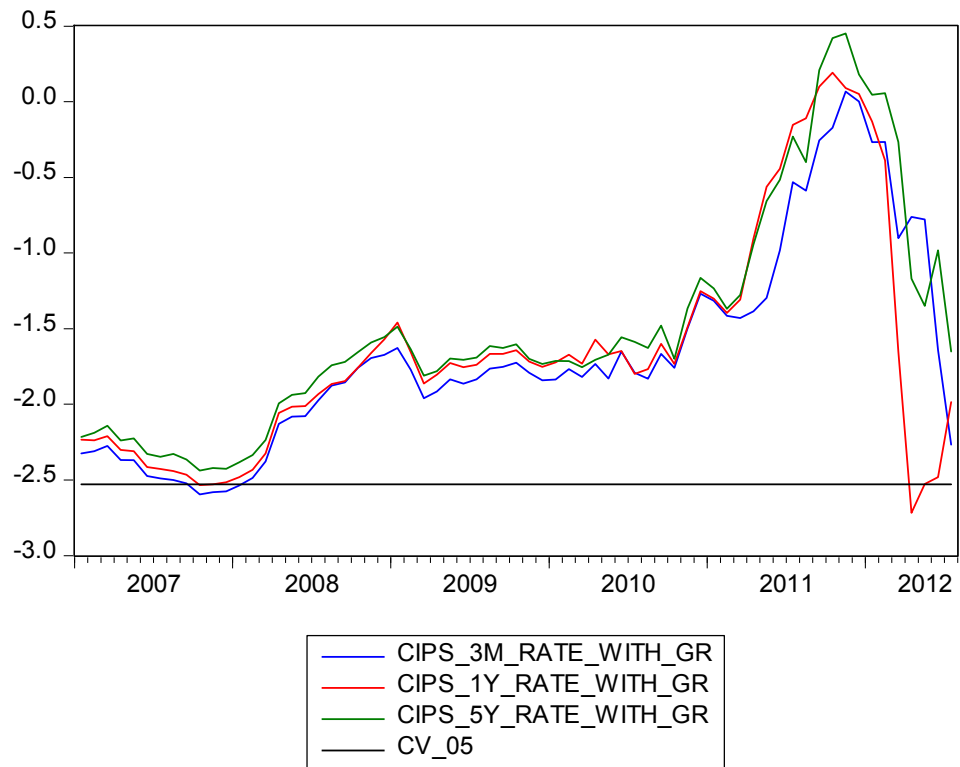
Figure 3: Recursive CIPS test statistics of *ex post* real interest rates.



Notes: The starting date is 2007m1. CV_05 is 5% critical value (for $T=100$, $N=10$, and $\hat{p} = [4(T/100)^{1/4}] = 4$). For more details, see Table 2.

Figure 4: Recursive CIPS test statistics of *ex post* real interest rates.

(include Greece, $N=11$)



References

- Atkins, F.J., Coe, P.J., 2002. An ARDL bounds test of the long-run Fisher effect in the United States and Canada. *Journal of Macroeconomics* 24 (2), 255-266.
- Baltagi, B.H., Bresson, G., Pirotte A., 2007. Panel unit root tests and spatial dependence. *Journal of Applied Econometrics* 22, 339–360.
- Banerjee, A., Lumsdaine, R.L., Stock, J.H., 1992. Recursive and sequential test of the unit-root and trend-break hypotheses: theory and international evidence, *Journal of Business and Economics Statistics* 10, 271-287.
- Camarero, M., Carrion-i-Silvestre, J. Ll., Tamarit, C., 2010. Does real interest rate parity hold for OECD countries? New evidence using panel stationarity tests with cross-section dependence and structural breaks. *Scottish Journal of Political Economy* 57, 568-590.
- Carpenter, S., Demiralp, S., Senyuz, Z., 2012. Volatility in the federal funds market and money market spreads during the financial crisis, *Journal of Financial Stability*, forthcoming.
- Carpenter, S., Demiralp, S., Senyuz, Z., 2016. Volatility in the federal funds market and money market spreads during the financial crisis, *Journal of Financial Stability*, forthcoming.
- Carpenter, S., Demiralp, S., Schlusche, B., Senyuz, Z., 2014. Measuring stress in money markets: a dynamic factor approach, *Economics Letters*, 125, 101-106.
- Carpenter, S., Demiralp, S., Eisenschmidt, J., 2014. The effectiveness of non-standard monetary policy in addressing liquidity risk during the financial crisis: the experiences of the Federal Reserve and the European Central Bank, *Journal of Economic Dynamics and Control*, 43, 107-129.

- Chinn, M.D., Ito, H., 2008. A new measure of financial openness. *Journal of Comparative Policy Analysis*, Volume 10 (3), 309-322. (Update 2011 at http://web.pdx.edu/~ito/Chinn-Ito_website.htm)
- Chung, H., Laforte J.-P., Reifschneider, Williams, J.C. 2012. Have we underestimated the likelihood and severity of zero lower bounds events? *Journal of Money, Credit, and Banking*, Supplement, 44 (1), 47-82.
- Costantini, M., Lupi, C., 2007. An analysis of inflation and interest rates. New panel unit root results in the presence of structural breaks. *Economics Letters*, 95, 408-414.
- Crowder, W.J., Hoffman, D.L., 1996. The long-run relationship between nominal interests and inflation: the Fisher equation revisited. *Journal of Money, Credit, and Banking* 28 (1), 103-118.
- Didier, T., Hevia, C., Schmukler, S., 2012. How Resilient and Countercyclical were Emerging Economies during the Global Financial Crisis?, *Journal of International Money and Finance*, 1-26
- Evans, M.D.D., Lewis, K.K., 1995. Do expected shifts in inflation affect estimates of the long-run Fisher relation? *Journal of Finance* 50 (1), 225-253.
- Fisher, I., 1930. *The Theory of Interest*. Macmillan, New York.
- Eisenschmidt, J., Tapking, J., 2009. Liquidity risk premia in Unsecured interbank money markets, European Central Bank Working Paper No: 1025.
- Fahr, S., Motto, R., Rostagno, M., Smets, F., Tristani, O., 2011. A monetary policy strategy in good and bad times: lessons from the recent past, European Central Bank Working Paper No: 1336.

- Fama, E., 1975. Short-term interest rates as predictors of inflation. *American Economic Review* 65, 269-82.
- Gambacorta, L., Marquez-Ibanez, D., 2011. The Bank lending channel: lessons from the crisis, European Central Bank Working Paper No: 1335.
- Hansen, L.P., Singleton, K.J., 1983. Stochastic consumption, risk aversion, and the temporary behavior of asset returns. *Journal of Political Economy* 91 (2), 249-265.
- Im, K., Pesaran, H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels, *Journal of Econometrics* 115 (1), 53-74.
- Lai, K.S., 2008. The puzzling unit root in the real interest rate and its inconsistency with intertemporal consumption behavior, *Journal of International Money and Finance* 27, 140-155.
- Lanne, M., 2001. Near unit root and the relationship between inflation and interest rates: a reexamination of the Fisher effect. *Empirical Economics* 26 (2), 357-366.
- Lenza, M., Pill, H., Reichlin, L., 2010. Orthodox and Heterodox Monetary Policies, *Economic Policy*, 296-339.
- Lucas, R.E., 1978. Asset prices in an exchange economy. *Econometrica* 46 (6), 1429-1445.
- McAndrews, J., Sarkar, A., and Wang, Z., 2008, The effect of the term auction facility on the London Inter-Bank Offered Rate, FRB New York Staff Report 335(July).
- Mishkin, F.S., 1981. The real interest rate: an empirical investigation. *Carnegie-Rochester Conference Series on Public Policy* 15, 151-200.
- Mishkin, F.S., 1995. Nonstationarity of regressors and test on real-interest-rate behavior. *Journal of Business and Economic Statistics* 13 (1), 47-51.

- Neely, C.J., Rapach, D.E., 2008. Real interest rate persistence: evidence and implications. Federal Reserve Bank of St. Louis Review 90 (6), 609-642.
- Pesaran, M.H., 2004. General diagnostic tests for cross section dependence in panels. Cambridge Working Papers in Economics No. 435, University of Cambridge.
- Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics 22 (2), 265–312.
- Pesaran, M.H., 2015. Testing weak cross-sectional dependence in large panels, Econometric Reviews 34, 1089-1117.
- Pesaran, M.H., Smith, L.V., Yamagata, T., 2013, Panel unit root tests in the presence of a multifactor error structure, Journal of Econometrics 175, 94-115.
- Rapach D.E., Weber CE. 2004. Are real interest rates really nonstationary? New evidence from tests with good size and power. Journal of Macroeconomics 26: 409–430.
- Romer, D., 1996. Advanced Macroeconomics. McGraw-Hill, New York.
- Rose, A.K., 1988. Is the real interest rate stable? Journal of Finance 43 (5), 1095-1112.
- Sarafidis, V., Wansbeek, T., 2012. Cross-sectional dependence in panel data analysis, Econometric Reviews 31(5), 483-531.
- Shiller, R.J., 1979, The volatility of long-term interest rates and expectations models of the term structure. Journal of Political Economy 87, 1190-1219.
- Taylor, J., and Williams, J., 2009, A black swan in the money market, American Economic Journal: Macroeconomics 1(1), 58–83.
- Wallace, M.S., Warner, J.T., 1993. The Fisher effect and the term structure of interest rates: Tests of cointegration. Review of Economics and Statistics 75 (2), 320–324.

Wu, T., 2008, On the effectiveness of the Federal Reserve's new liquidity facilities, Federal Reserve Bank of Dallas Working Paper 08.

Appendix: Robustness analysis with the small sample⁹

The appendix provides a robustness analysis comparing the sensitivity of the results to the use of *ex-post* real interest rates vs. *ex-ante* real interest rates. Figure A1 shows the recursive CIPS test statistics of *ex-ante* real interest rates, using data on inflation expectations to construct real interest rates. Shorter term interest rates appear to be non-stationary for the small sample. The five year rate appears to be more stable in the period before 2010. Figure A2 shows the corresponding results obtained with *ex-post* real interest rates. Here, we observe that while short term as well as long term rates appear to be stationary before 2010, they become nonstationary afterwards. Our findings suggest that the results are generally insensitive to the use of *ex-post* real interest rates.

⁹ The small sample includes Germany, France, Italy, Netherlands, and Spain for which data on inflation expectations are available.

Figure A1: Recursive CIPS test statistics of *ex-ante* real interest rates.

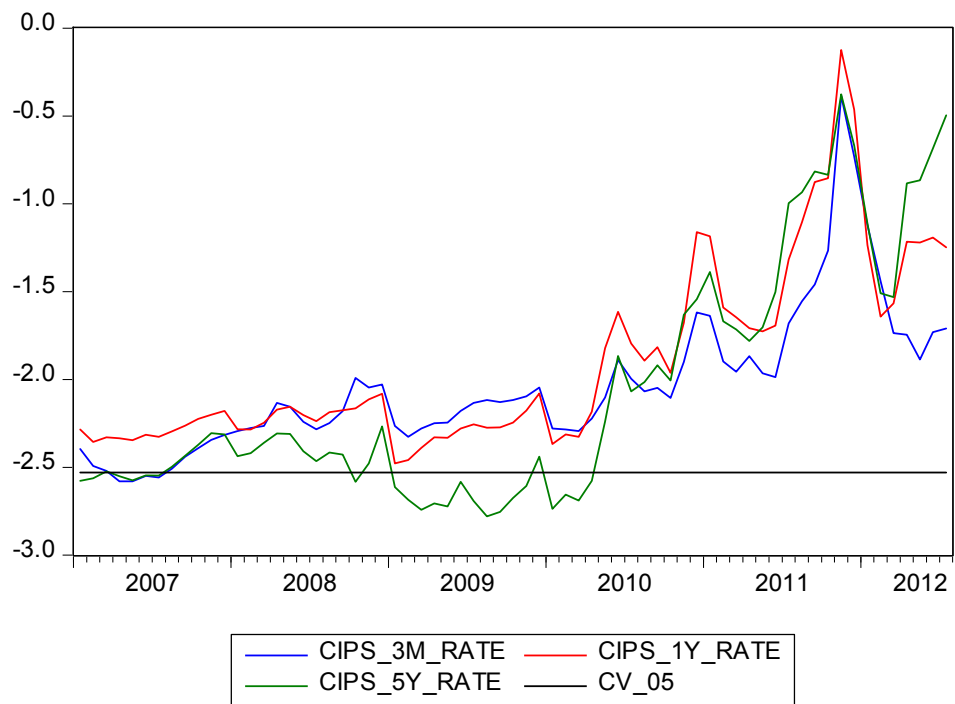


Figure A2: Recursive CIPS test statistics of for *ex-post* real interest rates.

