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How did the Financial Crisis affect the Real Interest Rate Dynamics in Europe?*

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Abstract

We investigate the effects of the financial crisis on the stationarity of real interest rates in the Euro Area. We use a new unit root test developed by Peseran et al. (2013) that allows for multiple unobserved factors in a panel set up. Our results suggest that while short-term and long-term real interest rates were stationary before the financial crisis, they became non-stationary during the crisis period likely due to persistent risk that characterized financial markets during that time.

JEL codes: E43, C23

Keywords: Real interest rates, Euro Area, financial crisis, panel unit root tests, cross-sectional dependence.

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1. Introduction

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.

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

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 European countries with lax capital controls and common monetary policy. In particular, we adopt a panel framework and utilize a flexible 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 *m* common factors instead. We believe that an *m* 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 real interest rates. 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.

The argument of common real interest rate dynamics is primarily driven by the fact that most countries in our dataset are the 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) such as the Euro Area countries (Austria, Belgium, France, Germany, Ireland, Italy, Netherlands, Portugal, Spain) as well as Denmark.[2] We later test this assumption formally and illustrate that there is strong evidence of common cross sectional dynamics in our sample.

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. Within this period, we consider sub-sample analysis to investigate the effects of the recent financial crisis on real interest rate dynamics. Our relatively short panels decrease the possibility of structural breaks in the sample, the presence of which could be a potential reason for the false detection of unit roots with standard tests (see Lai, 2008, and the references therein).

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 interest rates due to elevated risks and high persistence reflected in risk premia during that time.

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

[2] Even though Denmark does not use the Euro, its national currency, Krone, is pegged to the Euro. Hence, the National Bank of Denmark closely tracks the changes made by the European Central Bank.

methodology of panel unit root tests that is employed in this study. The fourth section concludes.

2. Empirical Framework

2.1 *Determination of Real Interest Rates*

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

$$i_t = r_t + \pi_t^e \tag{1}$$

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:

$$r_t = i_t - \pi_t^e \tag{2}$$

We use equation (2) to construct real interest rate series in our analysis. The nominal interest rate on a term loan, i_t, has three major components: the expected average overnight risk-free interest rate, the term premium, and the risk premium. Meanwhile, inflation expectations, π_t^e, are driven by long-term monetary policy expectations. We view these components as the potential common factors that drive short-term and long-term real interest rates in our analysis.

For the short-term interest rate, we use the three-month government bond rates, which should not contain any term premium. Turning to the risk premium, this variable has two components: credit and liquidity risks. While these risk factors are believed to be rather small during the period before the financial crisis as shown by various measures such as the Libor-OIS spread, they were both elevated during the crisis (see e.g.Taylor and Williams, 2009, McAndrews et al., 2009, Wu, 2008). Table 1 summarizes the common factors that we believe to be potentially present in our real interest rate series. Accordingly, we expect short-term monetary policy expectations to be present in both short-term as well as long-term interest rates as a proxy for the risk-free overnight interest rate. Because most countries in our sample are in the Euro system, common monetary policy expectations in this region are well justified. Long-term monetary policy expectations, which drive inflation expectations, should be present in long-term interest rates. As for short-term interest rates, we believe that inflation expectations should be negligible over a three-month horizon and hence can be ignored. We expect the risk premium to be present in both maturities, although its impact is likely much larger during the crisis period. Long-term interest rates should also be affected by the term premium due to their longer maturities.

This line of reasoning suggests that we should consider a framework that allows for more than one common factor in our empirical analysis: at most two common factors for short-term interest rates (short-term monetary policy expectations and risk premium) and four common factors for long-term interest rates (short-term monetary policy expectations, long-term monetary policy expectations, risk premium, and term premium). Hence, the recent methodology developed by Pesaran et al. (2013) is the most suitable one for our purposes.

2.2 *The Data*

Our dataset includes short-term (3-month) and long-term (1-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 Federal Reserve Economic Data (FRED). 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.[3] For that small sample, the forecast error between the expected and the realized interest rates is found to be stationary based on Peseran et al (2013) test (not shown), providing support for the use of realized inflation rate as a substitute for inflation expectations. Furthermore, due to obvious problems regarding the reliability of the data on inflation expectations (because it has to be based on either a survey or an econometric forecast), 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 exchange rates, stock price volatility (VSTOXX), and the 12-month Overnight Index Swap (OIS) rate.

3. Empirical Analysis

3.1 *Methodology*

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 the panel unit root tests of Peseran et al. (2013).

[3] These countries are Germany, France, Italy, Netherlands, and Spain.

We believe that this way of conducting the stationarity test has its advantages over the alternative approach where researchers focus on the stationarity properties of the nominal interest rate and the inflation rate separately (see e.g. Rose, 1988, Rapach and Weber, 2004). Specifically, given that the aforementioned variables are non-stationary, a freely estimated cointegrating vector between them by itself does not imply stationary of the real interest rate. Besides, the alternative approach typically has less power to reject the null of no cointegration when the true cointegrating vector is $(1,-1)'$.

We utilize the cross-sectionally augmented Dickey-Fuller (DF) regression (see Eq. (19) in Pesaran et al. (2013)):

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

for $i = 1,...,N; t = 1,...,T$

where y_{it} is the real interest rate in country i in month t. The vector $x_{it} = (x_{1it}, \ldots, x_{kit})'$ is a $k \times 1$ vector of additional regressors, which are assumed to share common factors with the real interest rate series. That is, the additional regressors may help us recover useful information about the common factors. Note that the above equation 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 the individual additional regressors $(\bar{x}_{1t} = N^{-1}\sum_{j=1}^{N} x_{1jt}\ , \ \ldots\ , \ \bar{x}_{kt} = N^{-1}\sum_{j=1}^{N} x_{kjt})$. In our application, the regressor vector x_{it} generally includes time series data such as exchange rates, stock market volatility, or the 12-month OIS rate.

In this set up, the 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 some 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 $H_0: b_i = 0$, $\forall$ i (non-stationary process) against the alternative $H_1: b_i < 0$, for at least some *i* (partially stationary process).[4]

The above cross-sectionally augmented DF regression can be further augmented with lagged changes $\Delta y_{it-s}, \Delta \bar{y}_{t-s}, \Delta x_{1it-s}, \Delta \bar{x}_{1t-s}, \ldots, \Delta x_{kit-s}, \Delta \bar{x}_{kt-s}$ ($s = 1, \ldots, p$) 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. 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. Thus, the IPS test serves as a natural benchmark to compare our results with.

3.2 *Results*

Before considering the CIPS test, it is important to determine whether the cross-sectional dependence is statistically significant to see whether the data is suitable to apply the Pesaran et al. (2013)'s test. To that end, we estimated individual ADF(*p*) regressions (without cross-sectional augmentations) and calculated pair-wise cross-sectional correlations of the residuals

[4] 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 $N \to \infty$.

from these regressions, $\hat{\rho}_{ij}$. Then, we calculated the average across all pairs, $\bar{\hat{\rho}} = (2/N(N-1))\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}$ and the associated cross-sectional dependence (CD) statistic of Pesaran (2004), $CD = (TN(N-1)/2)^{1/2}\,\bar{\hat{\rho}}$.

The results for the pre-crisis sample (January 1999 through July 2007) are shown in columns 1-4 in Table 2 while the results for the post-crisis sample (August 2007 through July 2012) are shown in columns 5-8. In this table, we report the results for up to three lags ($p \leq 3$) to capture alternative autoregressive dynamics at the monthly frequency. The results indicate strong evidence of cross-sectional dependence with the long-term interest rates being more interdependent. This verifies the use of the Pesaran et al. (2013)'s unit root tests where the average cross-section correlation, $\bar{\hat{\rho}}$, is around 29 percent for short-term (3-month) interest rates, and higher for long-term (1-year) interest rates. This finding supports the argument of common real interest rate dynamics for our sample of ten countries.

The analysis is conducted for short-term as well as long-term interest rates. As pointed out by Wallace and Warner (1993), integration properties of short-term bonds are expected to pass through to long-term bonds, yielding common dynamics. Long-term interest rates are particularly interesting because they are widely believed to be the most relevant factor for savings and investment decisions (Rapach and Weber, 2004). Nevertheless, as we have discussed in Table 1, short-term and long-term interest rates may have different common factors that needs to be incorporated in the analysis.

Armed with this evidence, Table 3 displays the results of hypothesis tests under the assumption of cross sectional dependence. Once again, we conduct the test under different lag structures for up to three lags to consider alternative dynamic properties of the data. Furthermore, we present the results for a different number of common factors (m^0) in panels (a) through (c). Recall that we expect two common factors, i.e. short-term monetary policy expectations and risk premium for short-term interest rates, and four common factors for long-term interest rates with the addition of the term premia and long-term monetary policy expectations.

Columns 1-4 show the results for the pre-crisis sample. A quick look at panels (a) through (c) reflects that the test results show some sensitivity to the number of common factors that are assumed to be present in the underlying series. Panel (a) illustrates the results with one common factor ($m^0 = 1$), panel (b) shows the results with two common factors ($m^0 = 2$) while panel (c) shows the results with four common factors ($m^0 = 4$). In order to conduct the Pesaran et al. (2013) methodology, we need to add $m^0 - 1$ exogenous regressors that are likely to share common factors with real interest rates. We consider the log of the exchange rate of the Euro in terms of US Dollars in time t, e_t, 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.[5] Before settling with these regressors, we also experimented with regressors

[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.

similar to the application in Peseran et al. (2013), oil prices and stock prices, but are found to be less useful in rejecting the null hypothesis.

For the pre-crisis period, we observe that with two common factors (panel (b)), there is strong evidence that short-term (3-month) interest rates are stationary regardless of the underlying regressor that is used to identify the common factors (i.e. e_t, $OIS12_t$, or $VSTOXX_t$). Similarly, long-term (1-year) interest rates are also stationary for the period before the financial crisis, under the assumption of four common factors (panel (c)).

Our findings highlight that the failure to incorporate a rich dynamic structure with *m* dynamic factors may lead to inconclusive evidence regarding the stationarity features of interest rates. Indeed, if we only assume one common factor (panel (a)) for short-term and long-term interest rates, we do not reach conclusive evidence regarding the stationarity of interest rates during the period before the financial crisis.

To check the importance of allowing for cross-sectional dependence, Table 4 reports the results of IPS test which does not incorporate any cross sectional dependence. Once the cross sectional dependence assumption is removed, we fail to reject the null hypothesis of non-stationarity across all alternative lag structures. This finding suggests that failure to incorporate cross-sectional dependence in the unit root tests may generate misleading results. Indeed, Baltagi et al. (2007) examine the relative performance of several panel unit root tests under spatial dependence (a form of cross-sectional dependence) and illustrate that in the presence of cross-sectional dependence, earlier panel unit root tests (e.g., Im et al., 2003) suffer from considerable size distortions.

Columns 5-8 show the results for the crisis period. In Table 2, we had established evidence in favor of cross sectional dependence. When we move to Table 3, we observe that neither short-term (panel (b)) nor long-term interest rates (panel (c)) are stationary during this period, likely due to panic and elevated risk that dominated this period. On the contrary, Table 4 shows that in the absence of cross sectional dependence assumption, all interest rate series seem to be stationary. Once again, this could reflect the fact that failing to incorporate cross sectional dependence (when it is present) leads to misleading results regarding the stationarity of the underlying series.

Altogether, our findings suggest that interest rates in the Euro area were stationary prior to the crisis period consistent with the Fisher hypothesis or the consumption based intertemporal models of asset prices. The financial crisis radically changed 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, term and risk premia, as well as cross sectional dependence 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 driven by the persistent risk premium that reached historically high levels during this period.

Table 1: Potential common factors

Short-term interest rate	• Monetary policy expectations o Short-term • Risk premium

Long-term interest rate	• Monetary policy expectations
	  o Short-term
	  o Long-term
	• Risk premium
	• Term premium

Table 2: Tests for cross-sectional dependence of *ex post* real interest rates

		Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
		I.	II.	III.	IV.	V.	VI.	VII.	VIII.
		p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	CD	19.92***	19.75***	19.13***	18.66***	14.23***	14.70***	14.64***	14.60***
	$\bar{\hat{\rho}}$	0.293	0.290	0.281	0.274	0.274	0.283	0.282	0.281
1 y rate	CD	25.67***	25.22***	24.80***	23.94***	16.00***	16.31***	16.63***	16.68***
	$\bar{\hat{\rho}}$	0.377	0.370	0.364	0.351	0.308	0.314	0.320	0.321

Notes: CD is the cross-sectional dependence (CD) statistic of Pesaran (2007), which follows the standard normal distribution. $\bar{\hat{\rho}}$ is the average of the correlation coefficients across all $(10 \times 9)/2 = 45$ pairs. *** indicates significance at 99 percent level of confidence.

Table 3: Tests for nonstationarity of *ex post* real interest rates *with* cross-sectional dependence

a) Single common factor ($m^0 = 1$)

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.24*	-2.16	-2.08	-2.22*	-1.43	-1.59	-1.68	-1.86
1y rate	-2.30*	-2.35**	-2.19	-2.30*	-1.22	-1.37	-1.60	-1.74

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

b) Two common factors ($m^0 = 2$)

$\bar{x}_t = e_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	p=1	p=2	p=3	p=0	p=1	p=2	p=3
3m rate	-2.59**	-2.64***	-2.51**	-2.57**	-1.61	-1.66	-1.68	-1.88
1y rate	-2.71***	-2.81***	-2.62***	-2.70***	-1.26	-1.22	-1.39	-1.66

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

$\bar{x}_t = OIS12_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	p=1	p=2	p=3	p=0	p=1	p=2	p=3
3m rate	-2.83***	-2.65***	-2.48**	-2.57**	-1.91	-1.89	-1.87	-2.01
1y rate	-2.76***	-2.65***	-2.43**	-2.56**	-1.27	-1.43	-1.69	-1.86

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

$\bar{x}_t = VSTOXX_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	p=1	p=2	p=3	p=0	p=1	p=2	p=3
3m rate	-2.69***	-2.50**	-2.38*	-2.39*	-1.21	-1.30	-1.31	-1.49
1y rate	-2.77***	-2.67***	-2.42**	-2.45**	-0.88	-0.96	-1.11	-1.33

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

c) Four common factors ($m^0 = 4$)

$\bar{x}_t = VSTOXX_t, e_t, OIS12_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-3.60***	-3.34***	-3.16***	-3.14***	-1.88	-1.94	-1.61	-1.59
1y rate	-3.41***	-3.14***	-2.93**	2.97***	-1.45	-1.37	-1.38	-1.57

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

Notes: The CIPS statistic is the cross-sectional augmented panel unit root of Pesaran et al (2013). m^0 is the number of factors while the variables in $\bar{x}_t$ are the regressors used for cross section augmentation along with $\bar{y}_t$. $VSTOXX_t$ is the volatility index, e_t is the logarithm of the exchange rate of the Euro in terms of US Dollars in time t, while $OIS12_t$ is the 12-month OIS rate. A constant term is included in the test regression.

Table 4: Tests for nonstationarity of *ex-post* real interest rates *without* cross-sectional dependence

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-1.23	-1.39	-1.32	-1.42	-1.92*	-2.01**	-2.01**	-2.01**
1y rate	-1.16	-1.35	-1.30	-1.47	-2.03**	-2.13**	-2.21***	-2.16***

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

Notes: The *t*-bar statistics of Im et al. (2003) are reported. A constant term is included in the test regression.

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 Gç, Pirotte A., 2007. Panel unit root tests and spatial dependence. Journal of Applied Econometrics 22(2), 339–360.

Chinn, M, D. and 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)

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.

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.

Eugene F. Fama. "Short-term interest rates as predictors of inflation." *American Economic Review* 65 (June 1975), 269-82.

Fisher, I., 1930. The Theory of Interest. Macmillan, New York.

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.

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).

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.

Lucas, R.E., 1978. Asset prices in an exchange economy. Econometrica 46 (6), 1429-1445.

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.

Peseran, M.H., 2004. General diagnostic tests for cross section dependence in panels. Cambridge Working Papers in Economics No. 435, University of Cambridge.

Peseran, 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., Smith, L.V., Yamagata, T., 2013, Panel unit root tests in the presence of a multifactor error structure, Journal of Econometrics, forthcoming.

Rapach DE, 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

In this section, we investigate the sensitivity of our results to the use of *ex-post* real interest rates. First, we redo our analysis for a subset of countries (Germany, France, Italy, Netherlands, and Spain) using *ex-ante* real interest rates, utilizing the available data on inflation expectations. We then repeat the analysis for the same five countries, this time using *ex-post* real interest rates as in the baseline analysis in the main text. Comparing the results from these experiments allows us to determine whether our results are sensitive to the use of *ex-post* real interest rates as a proxy for *ex-ante* real interest rates.

Tables A.1-A.3 show the results for the subset using *ex-ante* real interest rates. Similar to the baseline analysis, columns 1-4 show the results for the pre-crisis sample while columns 5-8 show the results for the crisis sample. For the pre-crisis period, there is evidence for cross sectional dependence (Table A.1), evidence of stationarity of short-term interest rates (Table A.2, panel (b)) and evidence of non-stationarity of long-term interest rates (Table A.2, panel (c)). Any evidence of stationarity disappears if we fail to incorporate cross sectional dependence (Table A.3).

During the crisis period, we observe that the dominant finding is the non-stationarity of both rates.[7] When we drop the assumption of cross sectional dependence, we find that short-term interest rates are non-stationary while long-term rates are stationary during this period.

Tables A.4-A.6 show the corresponding results using *ex-post* real interest rates. We observe an overall consistency with the results using *ex-ante* real interest rates. There is evidence for cross sectional dependence (Table A.4). Short-term interest rates are stationary for

[7] Even though there is some mild evidence of stationarity of short-term real interest rates when we use e_t as the exogenous regressor (for p=1 or p=2), such evidence disappears when we use $OIS12_t$ or $VSTOXX_t$.

the pre-crisis sample, and non-stationary for the post-crisis sample (Table A.5, panel (b)), similar to our findings using *ex-ante* real interest rates. Meanwhile, long-term interest rates are stationary for the pre-crisis sample even though they were non-stationary when we used *ex-ante* interest rates for that period. For the crisis period, however, they are non-stationary and once again consistent with the findings using *ex-ante* interest rates (Table A.5, panel (c)). Evidence of stationarity is reversed when we do not incorporate cross sectional dependence (Table A.6).

Overall, our analysis in this appendix highlights the strong consistency between the results using *ex-ante* vs. *ex-post* real interest rates for the subset of countries for which data on inflation expectations is available. This finding reassures us that our analysis in the main text is not distorted due to the use of actual inflation rate in place of inflation expectations.

Appendix: Robustness analysis with the small sample[8]

Table A.1: Tests for cross-sectional dependence of *ex-ante* real interest rates

		Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
		I.	II.	III.	IV.	V.	VI.	VII.	VIII.
		p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	CD	22.22***	21.61***	21.67***	21.75***	13.05***	13.54***	13.49***	12.91***
	$\bar{\hat{\rho}}$	0.69	0.67	0.68	0.68	0.53	0.55	0.55	0.53
1 y rate	CD	23.48***	22.38***	22.41***	22.44***	13.54***	13.85***	13.41***	13.27***
	$\bar{\hat{\rho}}$	0.73	0.70	0.70	0.70	0.55	0.57	0.55	0.54

Notes: CD is the cross-sectional dependence (CD) statistic of Pesaran (2007), which follows the standard normal distribution. $\bar{\hat{\rho}}$ is the average of the correlation coefficients across all $(5\times 4)/2 = 10$ pairs. *** indicates significance at 99 percent level of confidence.

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

Table A.2: Tests for nonstationarity of *ex-ante* real interest rates *with* cross-sectional dependence

a) Single common factor ($m^0 = 1$)

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-3.20***	-3.12***	-2.78***	-2.66***	-2.18	-2.95***	-2.52**	-2.25
1y rate	-2.69***	-2.64***	-2.51**	-2.52**	-2.13	-2.67***	-2.48**	-2.09

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

b) Two common factors ($m^0 = 2$)

$\bar{x}_t = e_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.63***	-2.69***	-2.68***	-2.68***	-2.11	-2.84***	-2.51**	-2.10
1y rate	-2.21	-2.20	-2.34*	-2.36*	-2.05	-2.63***	-2.44**	-2.05

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

$\bar{x}_t = OIS12_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-3.13***	-3.22***	-2.90***	-2.82***	-1.53	-2.25	-1.73	-1.45
1y rate	-2.29	-2.59***	-2.67***	-2.73***	-1.29	-2.16	-1.59	-1.15

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

$\bar{x}_t = VSTOXX_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.78***	-2.87***	-2.70***	-2.67***	-1.32	-1.82	-0.70	-0.57
1y rate	-2.15	-2.15	-2.11	-2.20	-1.22	-1.62	-0.78	-0.48

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

d) Four common factors ($m^0 = 4$)

$\bar{x}_t = VSTOXX_t$, e_t , $OIS12_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.66	-2.78**	-2.79**	-2.84**	-1.18	-1.62	-0.47	-0.43
1y rate	-1.99	-2.03	-2.31	-2.42	-1.14	-1.52	-0.54	-0.35

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

Notes: The CIPS statistic is the cross-sectional augmented panel unit root of Pesaran et al (2013). m^0 is the number of factors while the variables in $\bar{x}_t$ are the regressors used for cross section augmentation along with $\bar{y}_t$. $VSTOXX_t$ is the volatility index, e_t is the logarithm of the exchange rate of the Euro in terms of US Dollars in time t , while $OIS12_t$ is the 12-month OIS rate. A constant term is included in the test regression.

Table A.3: Tests for nonstationarity of *ex-ante* real interest rates *without* cross-sectional dependence

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-0.94	-1.18	-1.26	-1.24	-1.87	-2.01*	-1.98	-1.72
1y rate	-0.89	-1.26	-1.47	-1.46	-2.09*	-2.21**	-2.27**	-1.95

*/** indicates that the null hypothesis of non-stationarity is rejected at 90/95 percent level of confidence.

Notes: The *t*-bar statistics of Im et al. (2003) are reported. A constant term is included in the test regression.

Table A.4: Tests for cross-sectional dependence of *ex-post* real interest rates

		Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
		I.	II.	III.	IV.	V.	VI.	VII.	VIII.
		p=0	p=1	p=2	p=3	p=0	p=1	p=2	p=3
3m rate	CD	10.48***	10.14***	9.73***	9.30***	8.30***	9.06***	8.89***	8.62***
	$\bar{\hat{\rho}}$	0.33	0.32	0.30	0.29	0.34	0.37	0.36	0.35
1 y rate	CD	12.69***	12.29***	12.07***	11.27***	8.53***	9.06***	8.92***	8.91***
	$\bar{\hat{\rho}}$	0.40	0.38	0.38	0.35	0.35	0.37	0.36	0.36

Notes: CD is the cross-sectional dependence (CD) statistic of Pesaran (2007), which follows the standard normal distribution. $\bar{\hat{\rho}}$ is the average of the correlation coefficients across all $(5\times 4)/2=10$ pairs. *** indicates significance at 99 percent level of confidence.

Table A.5: Tests for nonstationarity of *ex-post* real interest rates *with* cross-sectional dependence

a) Single common factor ($m^0 = 1$)

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	p=1	p=2	p=3	p=0	p=1	p=2	p=3
3m rate	-2.13	-2.00	-1.89	-2.13	-1.97	-2.58**	-2.37*	-2.48**
1y rate	-2.14	-2.14	-2.05	-2.35*	-1.49	-2.24	-2.22	-2.33*

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

b) Two common factors ($m^0 = 2$)

$\bar{x}_t = e_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.80***	-2.62***	-2.45**	-2.71***	-2.09	-2.50**	-2.25	-2.29
1y rate	-2.81***	-2.76***	-2.58**	-2.88***	-1.55	-2.06	-1.98	-2.16

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

$\bar{x}_t = OIS12_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.42**	-2.26	-2.08	-2.38*	-1.95	-2.38*	-2.15	-2.40**
1y rate	-2.43**	-2.45**	-2.28	-2.70***	-1.41	-2.00	-1.84	-2.04

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

$\bar{x}_t = V2X_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-2.73***	-2.59***	-2.44**	-2.40*	-1.80	-2.37*	-1.94	-2.00
1y rate	-2.64***	-2.58**	-2.38*	-2.37*	-0.92	-1.62	-1.44	-1.61

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

e) Four common factors ($m^0 = 4$)

$\bar{x}_t = V2X_t,\ e_t, OIS12_t$

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-3.64***	-3.26***	-3.11***	-3.32***	-1.59	-2.14	-1.45	-1.46
1y rate	-3.15***	-3.03***	-2.92**	-3.19***	-0.90	-1.47	-0.91	-1.13

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

Notes: The CIPS statistic is the cross-sectional augmented panel unit root of Pesaran et al (2013). m^0 is the number of factors while the variables in $\bar{x}_t$ are the regressors used for cross section augmentation along with $\bar{y}_t$. $VSTOXX_t$ is the volatility index, e_t is the logarithm of the exchange rate of the Euro in terms of US Dollars in time *t*, while $OIS12_t$ is the 12-month OIS rate. A constant term is included in the test regression.

Table A.6: Tests for nonstationarity of *ex-post* real interest rates *without* cross-sectional dependence

	Pre-Crisis Sample January 1999-July 2007				Post-Crisis Sample August 2007-July 2012			
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
	p=0	*p*=1	*p*=2	*p*=3	*p*=0	*p*=1	*p*=2	*p*=3
3m rate	-0.94	-1.16	-1.02	-1.10	-2.08*	-2.25**	-2.11*	-2.01*
1y rate	-0.88	-1.11	-1.00	-1.20	-2.18**	-2.41***	-2.37***	-2.21**

*/**/*** indicates that the null hypothesis of non-stationarity is rejected at 90/95/99 percent level of confidence.

Notes: The *t*-bar statistics of Im et al. (2003) are reported. A constant term is included in the test regression.