

# Is the sovereign debt market efficient? Evidence from the US and German sovereign debt markets

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**Abstract** This paper analyses the efficient market hypothesis. It proposes a new method of testing the efficient market hypothesis based on the idea of Shiller (1979). Using a GARCH model, we test whether the excess volatility in the German and US sovereign debt markets is an indication of inefficient markets during different periods. The results indicate that omitting structural breaks may lead to wrong results. We find that although both debts were efficient during some periods and inefficient during other periods of time. Taking all periods together the financial markets appear to be inefficient. Hence, the general outcome was that both financial markets are not efficient markets.

**Keywords** Shiller volatility test · Efficient market hypothesis · Neoclassical economics · Bounded rationality · Applied econometrics

**JEL Classification** C2 · C5 · F3 · G14 · G15

## 1 Introduction

The dominant theory since the early to mid-1960s have been the efficient market hypothesis (EMH), developed through the contributions of prominence articles such as Malkiel (1962) and Fama (1965, 1970). However to a certain degree the efficient market hypothesis relies on some untestable assumptions and models. Yet it is possible to test the key assumptions of efficiency through the use of prominent tests like the Shiller volatility test proposed by Shiller (1981a).

The efficient market hypothesis is based upon the model of perfect competition which is the base of neoclassical economics. Perfect competition implies market participants are assumed to be rational, risk averse and profit maximising. This assumption of market participants' behaviour is extended into the efficient market hypothesis as developed by Fama (1965) and Malkiel (1962). Especially since the

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**Table 1** The 10-year sovereign debt prices data

Country	Reference number	Download date	Issue date	Maturity date
Germany 2012	DE0001135192	16/07/2012	02/01/2002	31/12/2011
Germany 2017	DE0001135317	08/04/2013	17/11/2006	04/01/2017
US 2012	9128277L0	16/07/2012	15/02/2002	15/02/2012
US 2017	912828GH7	08/04/2013	15/02/2007	15/02/2017

1990s (Shiller 2003) behavioural finance gained momentum questioning the efficient market hypothesis. As we are testing the efficient market hypothesis, we start this paper by a short review of the efficient market hypothesis. The next section explains the data used. Section 4 gives the empirical test. Section 5 presents the empirical results and Section 5 concludes.

## 2 Review of the efficient market hypothesis

According to Fama (1970) the efficient market is a market where investors are assumed to exhibit rational profit-maximization behaviour and prices always fully reflect available information. A consequence of this assumption is that new information spreads quickly and is priced into asset valuation without delay. Hence as Malkiel (2005) states this means that no arbitrage opportunities exists that allows for excess returns without excess risks. As Malkiel (2003) hints in an efficient market, competition will mean that opportunities for excessive risk adjusted returns will not persists. However, this does not mean that the efficient market hypothesis implies market prices will always be accurate and all investors will always exhibit rational profit maximization behaviour.

As suggested by both Fama (1965) and Malkiel (2003), the efficient market hypothesis is associated with the idea of the random walk theory. If bonds prices follow a random walk then they are unpredictable. Hence as Fama (1965) states during periods of uncertainty the equilibrium price can never be determined exactly or in other

**Table 2** Excess volatility test for the US

Observational period	Coefficients	Standard error	Test statistics	Statistics
2002 All	0.892517	0.560344	1.592800	1.96
2002–04	0.678227	0.840393	0.807036	1.96
2005–07	0.237236	0.132575	1.789447	1.96
2007–09	1.930796	0.223842	8.625718	1.96
2009–11	0.241801	0.017740	13.63029	1.96
2007 All	1.180680	1.067295	1.106235	1.96
2007–09	0.358914	1.444623	0.248448	1.96
2009–13	1.482435	0.419620	3.532803	1.96

words, the best forecast is to assume that tomorrow's price is the same as today's. As a result prices and returns are very difficult to forecast (Timmermann and Granger 2004).

Ball (2009) hints that believing in the EMH led to the false sense of security by regulators and investors that market prices are correctly based on all information especially in times prior to an asset price bubble. This could ultimately explain the financial crisis.

A key argument often put against the efficient market hypothesis is that sometimes asset prices deviate from the fundamental value as hinted by many including Barberis and Thaler (2003) and De Bondt et al. (2008). And as illustrated by Barberis and Thaler (2003) these deviations can be long-lived and substantial. Another issue raised by Hong and Stein (1999) is that market participants may not have all the fundamental information, and even if they do, as suggested by De Bondt (2000) and Daniel et al. (1998) they may have different sentiment about the information.

Another key argument is that because markets often go through phases where the efficient market hypothesis is not enough to explain the anomalies, e.g. bubbles (see Blanchard and Watson (1982); Hong and Stein (1999); De Bondt (2000); Abreu and Brunnermeier (2003)), there is a need to research the psychology of market participants as suggested by De Bondt et al. (2008) and Kourtidis et al. (2011). This points towards the use of the behavioural finance theory.

**Table 3** US 2012 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.004720	4.24E-05	111.3159	0.0000
VARIANCE (-1)	0.981295	0.000642	1527.623	0.0000
VRESID	0.714328	0.006116	116.8002	0.0000
Variance equation				
C	3.23E-08	9.73E-09	3.314462	0.0009
RESID (-1)^2	1.609716	0.124186	12.96213	0.0000
GARCH (-1)	0.282801	0.015724	17.98537	0.0000
T-DIST. DOF	4.388734	0.381358	11.50817	0.0000
R-squared		0.987422	Mean dependent var	0.348656
Adjusted R-squared		0.987412	S.D. dependent var	0.560344
S.E. of regression		0.062869	Akaike info criterion	-6.137893
Sum squared resid		9.711428	Schwarz cri terion	-6.121366
Log likelihood		7556.608	Hannan-Quinn criter.	-6.131888
Durbin-Watson stat		0.306380		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 27/10/13 Time: 06:56

Sample (adjusted): 29/07/2002 30/12/2011

Included observations: 2460 after adjustments

Convergence achieved after 54 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

In this paper, we will test the efficient market hypothesis from a different point of view. We are interested in the question whether EMH always holds or whether unforeseen and/or uncertain events such as the financial crisis leads to inefficient markets. We chose as sample markets the US and German bonds markets. We are particularly interested in the periods prior to the financial crisis 2008 and afterwards, which led to the Eurozone crisis. The hypothesis is therefore, that if we find only one period where the financial markets are inefficient then a financial market cannot be efficient as a whole.

### 3 Data

As illustrated by Table 1, we use the daily US Treasury 10-Year notes and German 10-year Bunds, maturing in 2012 and 2017, end of day bid prices obtained from Bloomberg. We follow the norm by defining our week as Monday to Friday. In order to make the observed data uniformed across both issues, we replace missing or not available prices with the last kno33wn price.

**Table 4** US 2012 Period 1 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	-0.001023	0.001509	-0.677810	0.4979
VARIANCE (-1)	1.007084	0.001980	508.5280	0.0000
VRESID	0.753532	0.012692	59.37071	0.0000
Variance equation				
C	0.000127	3.25E-05	3.909604	0.0001
RESID (-1)^2	1.503863	0.229540	6.551630	0.0000
GARCH (-1)	0.174364	0.034898	4.996397	0.0000
T-DIST. DOF	6.012264	1.547508	3.885125	0.0001
R-squared		0.980157	Mean dependent var	0.904144
Adjusted R-squared		0.980094	S.D. dependent var	0.840393
S.E. of regression		0.118570	Akaike info criterion	-2.708299
Sum squared resid		8.885146	Schwarz criterion	-2.659204
Log likelihood		866.8848	Hannan-Quinn criter.	-2.689236
Durbin-Watson stat		0.298753		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:30

Sample (adjusted): 29/07/2002 31/12/2004

Included observations: 635 after adjustments

Convergence achieved after 46 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

The two issues were chosen so that there would be an overlap in the observations. The first observed sample is from 1st July 2002 to 30th December 2011 with a total of 2480 daily observations. Our second sample is from 1st July 2007 to 31st March 2013 with a total of 1500 daily observations.

#### 4 The model specification of the shiller volatility test

The main aim of this research is to test for the efficient market hypothesis in the sovereign debt market for different periods of time. We opt to test for the EMH by using an extended version of the test originally proposed by Shiller (1979, 1981a), the Shiller Volatility Test.

While the Shiller volatility test, as stated by Shiller (1981b), is based on the key assumption that under the EMH prices incorporate the relevant market information efficiently, thus meaning excess volatility in the market is the result of inefficient markets as hinted by Bollerslev and Hodrick (1992) and Fama (1970). Hence it is essentially a test of the null hypothesis of the excess volatility in the market.

**Table 5** US 2012 Period 2 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.004392	0.000510	8.610362	0.0000
VARIANCE(-1)	0.981498	0.002108	465.6017	0.0000
VRESID	0.744302	0.016795	44.31566	0.0000
Variance equation				
C	2.69E-05	4.77E-06	5.640262	0.0000
RESID (-1)^2	1.143864	0.136782	8.362673	0.0000
GARCH (-1)	0.093372	0.029820	3.131151	0.0017
T-DIST. DOF	35.45637	43.30677	0.818726	0.4129
R-squared		0.977921	Mean dependent var	0.179593
Adjusted R-squared		0.977853	S.D. dependent var	0.132575
S.E. of regression		0.019730	Akaike info criterion	-5.751432
Sum squared resid		0.251855	Schwarz criterion	-5.703218
Log likelihood		1876.215	Hannan-Quinn criter.	-5.732731
Durbin-Watson stat		0.395152		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:30

Sample: 3/01/2005 29/06/2007

Included observations: 650

Convergence achieved after 53 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

We test for the null of the EMH using both the 2002 and 2007 set of observed prices. In order to analyse the different effects on the EMH in the context of different markets environment, we test for different periods within the 2002 and 2007 issues. To test the EMH for these periods, we use four subsamples across the observed datasets and test them separately. Given the large amount of observations (see below) there is no problem regarding degrees of freedom in the subsamples. So we test the EMH for the whole sample as well as for the subsamples.

The interesting consequence of this is that if a subsample is efficient that does not necessarily mean that the entire sample is efficient. We could have a scenario where over the whole period the market seems to be efficient but during a subsample the market is inefficient or the market could be inefficient but during a subsample the market is efficient. This then leads to the interesting question if and when the EMH holds and where there is any regularity.

In essence the influencing factor underpinning the Shiller volatility test as highlighted by Shiller (1979) is that on some occasions (e.g. crises) price volatility in the financial market exceeds that explained by efficient markets. Hence the markets are not efficient. Using the basis of the Shiller (1979) and LeRoy and Porter (1981) variance bound test methodology, we propose extending the test by using an AR-

**Table 6** US 2012 Period 3 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.004776	0.000202	23.65825	0.0000
VARIANCE (-1)	0.975373	0.001567	622.6356	0.0000
VRESID	0.702917	0.011493	61.15800	0.0000
Variance equation				
C	1.73E-06	7.57E-07	2.284426	0.0223
RESID (-1)^2	2.739762	0.722247	3.793387	0.0001
GARCH (-1)	0.191036	0.031928	5.983241	0.0000
T-DIST. DOF	2.972802	0.416539	7.136918	0.0000
R-squared		0.979268	Mean dependent var	0.259479
Adjusted R-squared		0.979200	S.D. dependent var	0.223842
S.E. of regression		0.032283	Akaike info criterion	-5.292438
Sum squared resid		0.632611	Schwarz criterion	-5.241792
Log likelihood		1621.194	Hannan-Quinn criter.	-5.272737
Durbin-Watson stat		0.424305		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:30

Sample: 2/07/2007 30/10/2009

Included observations: 610

Convergence achieved after 39 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

GARCH model in obtaining the key statistics (see also Musunuru 2014). By using the GARCH model, we omit the need for an optimal price and use the 5 % F-statistics to test the efficient market hypothesis directly.

In essence, the Shiller (1979, 1981a) and LeRoy and Porter (1981) variance bound test is really a test of whether the fundamental value as given by the present value equation, see Eq. 1, does determines the behaviour of the price. The basic argument, as put by Shiller (1992), is any excess volatility is evidence of inefficient markets. However as we will illustrate now there is a big issue regarding the use of the present value model within the bond market. The present value model dictates that the price of a bond based on all coupons is as given by Eq. 1.

$$P = \sum_{t=1}^T \frac{C \times PV}{\left(1 + \frac{r}{2}\right)^{2t}} + \frac{PV}{\left(1 + \frac{r}{2}\right)^{2T}} \tag{1}$$

Where C is the coupon rate, PV is the par value and r is the yield. The problem with this is from all these variables, the only time-varying variable is the yield. Whereas in the stock market the dividend is also time varying, hence the fundamental value of a stock is different from the price. However since the yield in the bond market is derived the price, this means that the price does not differentiate a lot from the fundamental

**Table 7** US 2012 Period 4 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.004641	0.000122	37.96292	0.0000
VARIANCE (-1)	0.981840	0.003607	272.1958	0.0000
VRESID	0.702702	0.018872	37.23473	0.0000
Variance equation				
C	3.57E-08	8.68E-09	4.117883	0.0000
RESID (-1)^2	0.991745	0.148589	6.674433	0.0000
GARCH (-1)	0.243627	0.047824	5.094201	0.0000
T-DIST. DOF	9.071400	2.559714	3.543912	0.0004
R-squared		0.984793	Mean dependent var	0.015123
Adjusted R-squared		0.984739	S.D. dependent var	0.017740
S.E. of regression		0.002192	Akaike info criterion	-11.67568
Sum squared resid		0.002699	Schwarz criterion	-11.62195
Log likelihood		3305.380	Hannan-Quinn criter.	-11.65471
Durbin-Watson stat		0.322144		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 01/05/14 Time: 06:38

Sample: 2/11/2009 30/12/2011

Included observations: 565

Convergence achieved after 25 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

value. So the problem in this model is that the price of the bond will always be approximating (if not equal to) the fundamental value. By omitting the need to calculate the fundamental value and using a simple AR(1)-GARCH (1,1). In order to analyse the efficiency in our observed markets, we need to calculate the daily variance. We use the 20 lag daily price variance in our statistical analysis and tests of the observed sovereign debt markets.

As illustrated by Shiller (1979), the key factor underlying the Shiller volatility test and any variance bound test is the variance calculation. We model our variables as time varying 20 lags variance of the price or excess returns using Eq. 2.

$$\lim_{t \rightarrow T} \text{var}(x_t) = \frac{\sum_{q=1}^Q (x - \mu)^2}{Q = 20} \tag{2}$$

The residuals are estimated using a one lagged autoregression model as illustrated by Eq. 3.

$$\text{var}(x_t) = \omega + \alpha_1 \text{var}(x_{t-1}) + \varepsilon_t \tag{3}$$

We set  $\epsilon$  to be equal to the residuals of the autoregression model. Hence the GARCH H is estimated using Eq. 4.

**Table 8** US 2017 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.009329	0.000173	53.85327	0.0000
VARIANCE (-1)	0.993947	0.000883	1125.839	0.0000
VRESID	0.717657	0.007993	89.78273	0.0000
Variance equation				
C	1.38E-06	4.27E-07	3.239528	0.0012
RESID (-1)^2	1.933987	0.224059	8.631583	0.0000
GARCH (-1)	0.246653	0.020714	11.90726	0.0000
T-DIST. DOF	3.724978	0.350357	10.63194	0.0000
R-squared		0.987786	Mean dependent var	0.706254
Adjusted R-squared		0.987769	S.D. dependent var	1.067295
S.E. of regression		0.118034	Akaike info criterion	-3.947830
Sum squared resid		20.56381	Schwarz criterion	-3.922750
Log likelihood		2926.421	Hannan-Quinn criter.	-3.938480
Durbin-Watson stat		0.349734		

Dependent Variable: VARIANCE  
 Method: ML - ARCH (Marquardt) - Student's t distribution  
 Date: 26/10/13 Time: 13:09  
 Sample (adjusted): 31/07/2007 29/03/2013  
 Included observations: 1479 after adjustments  
 Convergence achieved after 59 iterations  
 Presample variance: backcast (parameter=0.7)  
 GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)



$$\text{var}(x_t) = \omega + \alpha_1 \text{var}(x_{t-1}) + \epsilon_t \tag{4}$$

In common with all our GARCH models, we use t-student distribution; hence we estimate a t GARCH (1, 1) using Eq. 5

$$h_t = \omega + \alpha_1 k_{t-1} + \beta_1 h_{t-1} \tag{5}$$

We derive our EMH test by using the f-statistics; for our observed samples the f-statistics at the 5 % level is 1.96. We calculate our test statistics using Eq. 6

$$\text{statistics} = \frac{\text{coefficients}(\text{var}(x)) - 1}{\text{standard error}(\text{var}(x))} \tag{6}$$

Since the market is efficient when the statistics is equal or significantly close to the f-statistics, therefore by definition the market is efficient when the condition as set in Eq. 7 is true. Hence we reject the null hypothesis for the EMH if the condition is true but accept the null hypothesis of inefficient markets for anything else.

$$\text{abs}\left(\frac{\text{statistics}}{F\text{-statistics}}\right) \approx 1 \tag{7}$$

**Table 9** US 2017 Period 3 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	-0.000564	0.003340	-0.168886	0.8659
VARIANCE (-1)	1.006598	0.003128	321.8351	0.0000
VRESID	0.703845	0.014809	47.52759	0.0000
Variance equation				
C	0.000763	0.000151	5.037384	0.0000
RESID (-1)^2	1.238184	0.181054	6.838763	0.0000
GARCH (-1)	0.126311	0.045353	2.785038	0.0054
T-DIST. DOF	7.329484	2.206046	3.322453	0.0009
R-squared		0.984827	Mean dependent var	1.259843
Adjusted R-squared		0.984775	S.D. dependent var	1.444623
S.E. of regression		0.178249	Akaike info criterion	-2.128145
Sum squared resid		18.61874	Schwarz criterion	-2.076109
Log likelihood		633.7387	Hannan-Quinn criter.	-2.107872
Durbin-Watson stat		0.343291		

Dependent Variable: VARIANCE  
 Method: ML - ARCH (Marquardt) - Student's t distribution  
 Date: 26/11/13 Time: 10:43  
 Sample (adjusted): 31/07/2007 30/10/2009  
 Included observations: 589 after adjustments  
 Convergence achieved after 33 iterations  
 Presample variance: backcast (parameter=0.7)  
 GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

**Table 10** US 2017 Period 4 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.009385	0.000177	52.87950	0.0000
VARIANCE (-1)	0.987676	0.000946	1043.745	0.0000
VRESID	0.707102	0.010624	66.55923	0.0000
Variance equation				
C	1.61E-06	4.73E-07	3.407494	0.0007
RESID (-1)^2	2.317501	0.354558	6.536314	0.0000
GARCH (-1)	0.164934	0.021917	7.525326	0.0000
T-DIST. DOF	3.510722	0.412772	8.505226	0.0000
R-squared		0.984020	Mean dependent var	0.339891
Adjusted R-squared		0.983984	S.D. dependent var	0.419620
S.E. of regression		0.053105	Akaike info criterion	-5.231544
Sum squared resid		2.501457	Schwarz criterion	-5.193860
Log likelihood		2335.037	Hannan-Quinn criter.	-5.217140
Durbin-Watson stat		0.285361		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 26/11/13 Time: 10:43

Sample: 2/11/2009 29/03/2013

Included observations: 890

Convergence achieved after 181 i terations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

We use the F-statistics at the 5 % level of 1.96 to establish whether the market is too volatile to reject the null hypothesis of the EMH. There are two key statistics in the output of our GARCH model: the coefficient and standard error of the lagged price variance.

**Table 11** Excess volatility test for Germany

Observational period	Coefficients	Standard error	Test statistics	Statistics
2002 All	0.920398	0.216199	4.257179	1.96
2002-04	0.333321	0.313838	1.062079	1.96
2005-07	0.273525	0.088626	3.086388	1.96
2007-09	0.514787	0.133095	3.867817	1.96
2009-11	0.497084	0.013194	37.67500	1.96
2007 All	0.702752	0.344854	2.037824	1.96
2007-09	0.477713	0.397085	1.203049	1.96
2009-13	0.555505	0.257374	2.158361	1.96

In our test, the EMH test statistic is derived using equation 6. The Null of efficient markets in the observed period is accepted if the result is not exceeding 1.96, otherwise we reject the null hypothesis. Therefore we test the EMH for the overall market and for each period as identified above.

## 5 Empirical evidence

We test the prices of two US Treasury 10-Year notes and German Bunds observed over two periods, the first issue is from 1st July 2002 to 31st December 2011 and the second issue is from 1st July 2007 to 31st March 2013. In order to identify the changes in the market, we also test for the efficient markets in four sub-samples linked with different environments in the sovereign debt market. The first period is between August 2002 and December 2004 which was a highly volatile period mainly due to events ranging from the 11th September 2001 terrorist attacks and ensuing Afghanistan and Iraq wars to the collapse of the dotcom bubble and the ensuing recession. The second period, January 2005 to June 2007, mainly highlight low volatility in the sovereign debt market due to the bubbles in the housing and asset securitization such as MBS and CDO

**Table 12** German 2012 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.001963	2.46E-05	79.61863	0.0000
VARIANCE (-1)	0.990089	0.000685	1444.442	0.0000
VRESID	0.710886	0.006884	103.2691	0.0000
Variance equation				
C	3.25E-08	8.60E-09	3.785879	0.0002
RESID (-1)^2	1.683480	0.113878	14.78320	0.0000
GARCH (-1)	0.237050	0.014322	16.55150	0.0000
T-DIST. DOF	4.829455	0.397542	12.14830	0.0000
R-squared		0.983304	Mean dependent var	0.163322
Adjusted R-squared		0.983291	S.D. dependent var	0.216199
S.E. of regression		0.027947	Akaike info criterion	-6.910637
Sum squared resid		1.918996	Schwarz criterion	-6.894110
Log likelihood		8507.083	Hannan-Quinn criter.	-6.904632
Durbin-Watson stat		0.262916		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 30/10/13 Time: 05:52

Sample (adjusted): 29/07/2002 30/12/2011

Included observations: 2460 after adjustments

Convergence achieved after 51 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

**Table 13** German 2012 Period 1 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.001029	0.001081	0.951898	0.3411
VARIANCE (-1)	0.995465	0.003378	294.6592	0.0000
VRESID	0.782530	0.015692	49.86708	0.0000
Variance equation				
C	8.77E-05	1.49E-05	5.875950	0.0000
RESID (-1)^2	1.229532	0.170740	7.201172	0.0000
GARCH (-1)	0.103389	0.036378	2.842062	0.0045
T-DIST. DOF	10.73054	4.255253	2.521716	0.0117
R-squared		0.976096	Mean dependent var	0.347609
Adjusted R-squared		0.976020	S.D. dependent var	0.313838
S.E. of regression		0.048599	Akaike info criterion	-4.266761
Sum squared resid		1.492688	Schwarz criterion	-4.217666
Log likelihood		1361.697	Hannan-Quinn criter.	-4.247698
Durbin-Watson stat		0.284763		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:24

Sample (adjusted): 29/07/2002 31/12/2004

Included observations: 635 after adjustments

Convergence achieved after 67 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

markets brought on by the low interest rates and economic upturn. The third period, July 007 to October 2010, is highlighted by 2007/2008 financial crisis and ensuing economic recession. And the final period is between November 2010 and March 2013 highlighted by the sovereign debt crisis on both sides of the Atlantic.

We used EViews eight to estimate an AR(1)-GARCH(1, 1) model of the sovereign debt market volatility. This empirical section presents the results of or model of price volatility and the tests of the efficient market hypothesis in each period of the two 10-Year notes.

Table 2 gives the volatility test for the estimated GARCH models shown in Tables 3, 4, 5, 6, 7, 8, 9 and 10.<sup>1</sup> Where the test statistic is smaller than the critical value the market is efficient. The table shows is that if the entire sample is taken into account the market seems to be efficient for both US bond issues. If however the subsamples are considered then there are periods where the market is efficient and others where it is

<sup>1</sup> Tables 3, 4, 5, 6, 7, 8, 9 and 10 only show the regression results. We also tested for autocorrelation and normality of the residuals. We could not find autocorrelated behaviour and the residuals are normally distributed. The results are available from the authors upon request.

not. Notably the periods from 2007 to 2009 and 2009 to 2011 are not efficient for the 2002 bond. The results indicate that excess volatility was not present prior to 2005. From 2005 to 2007 volatility increases. So the build-up of the housing bubble is apparent in terms of higher volatility. The aftermath of the 2007 financial crisis also results in a higher volatility of the US government bonds. For the 2007 bond issue the results are similar although the excess volatility only starts in 2009.

As there are periods where the market is clearly not efficient, we cannot conclude that overall the bonds market is efficient. Moreover, it does not seem to be coincidental that the market is inefficient in times of crises and immediately before that. This points to the behavioural finance argument that in times of crises there are over- and/or under reactions of market participants.

The results for the German datasets are different to the US results as can be seen in Table 11. The tests in Table 11 are based on the estimated t GARCH (1,1) in Tables 12, 13, 14, 15, 16, 17, 18, 19. Table 11 shows that for the entire sample the test shows that the German bonds market is inefficient. This is in contrast to the US market. If this result is true then it highlights the limits of spillover effects in terms of one efficient market does not mean that other markets have to be efficient even though capital restrictions do not exist. However, as there are periods of inefficiency, this outcome of

**Table 14** German 2012 period 2 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.000729	0.000376	1.940021	0.0524
VARIANCE (-1)	1.025155	0.002561	400.3106	0.0000
VRESID	0.744072	0.017851	41.68134	0.0000
Variance equation				
C	9.64E-06	1.41E-06	6.831976	0.0000
RESID (-1)^2	1.161177	0.162107	7.163023	0.0000
GARCH (-1)	0.112348	0.034831	3.225488	0.0013
T-DIST. DOF	11.61559	4.841086	2.399378	0.0164
R-squared		0.972383	Mean dependent var	0.122495
Adjusted R-squared		0.972297	S.D. dependent var	0.098623
S.E. of regression		0.016415	Akaike info criterion	-6.464156
Sum squared resid		0.174333	Schwarz criterion	-6.415942
Log likelihood		2107.851	Hannan-Quinn criter.	-6.445455
Durbin-Watson stat		0.215801		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:25

Sample: 3/01/2005 29/06/2007

Included observations: 650

Convergence achieved after 62 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

the overall test may simply be a random/biased effect caused by ignoring structural breaks.

Looking at the subsamples there is a period where the market is efficient, namely from 2002 to 2004 for the 2002 bond issue and 2007–2009 for the 2007 bond issue. Interestingly, the periods of inefficiency are the same as in the case of the US. This would support the case of perfect capital mobility and linked markets.

Regardless, this result is not necessarily obvious as Germany was not as much affected by the housing bubble as the US (or indeed other European countries). But as investors were looking for safe havens, the volatility of German bonds markets could have increased due higher demand for government bonds.

As a result as in the case of the US, there are periods where the German financial market is efficient and there are other periods where it is not. Hence, one cannot conclude that the German financial market is always efficient, which means the German market is rather inefficient as in the case of the US.

Our contribution is therefore that we can show that there are mixed results. There are periods of time where markets are efficient and others where they are not. Hence, by not taking structural breaks into account, and testing over an entire sample one may conclude falsely that financial markets are efficient. However, testing over an entire

**Table 15** German 2012 Period 3 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.002287	0.000271	8.439395	0.0000
VARIANCE (-1)	0.973174	0.001752	555.4444	0.0000
VRESID	0.741932	0.015975	46.44398	0.0000
Variance equation				
C	3.71E-06	8.48E-07	4.379902	0.0000
RESID (-1)^2	1.314567	0.175964	7.470656	0.0000
GARCH (-1)	0.198202	0.037437	5.294243	0.0000
T-DIST. DOF	7.508520	2.087798	3.596382	0.0003
R-squared		0.979426	Mean dependent var	0.153214
Adjusted R-squared		0.979358	S.D. dependent var	0.133095
S.E. of regression		0.019122	Akaike info criterion	-6.233026
Sum squared resid		0.221952	Schwarz criterion	-6.182380
Log likelihood		1908.073	Hannan-Quinn criter.	-6.213325
Durbin-Watson stat		0.300485		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:25

Sample: 2/07/2007 30/10/2009

Included observations: 610

Convergence achieved after 59 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

**Table 16** German 2012 Period 4 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.002091	5.53E-05	37.83023	0.0000
VARIANCE (-1)	0.993474	0.001796	553.3078	0.0000
VRESID	0.763513	0.019155	39.85933	0.0000
Variance equation				
C	4.53E-08	9.45E-09	4.790642	0.0000
RESID (-1)^2	1.383852	0.193950	7.135088	0.0000
GARCH (-1)	0.113232	0.029609	3.824240	0.0001
T-DIST. DOF	7.071557	1.591842	4.442374	0.0000
R-squared		0.985310	Mean dependent var	0.014084
Adjusted R-squared		0.985257	S.D. dependent var	0.013194
S.E. of regression		0.001602	Akaike info criterion	-11.42098
Sum squared resid		0.001442	Schwarz criterion	-11.36725
Log likelihood		3233.428	Hannan-Quinn cri ter.	-11.40001
Durbin-Watson stat		0.228580		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 25/11/13 Time: 12:26

Sample: 2/11/2009 30/12/2011

Included observations: 565

Convergence achieved after 37 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

sample may not always result in showing that a market is efficient. As the German example has shown, the result can also be that the financial market overall is inefficient which is also wrong in the sense that it neglects the crucial information that there are periods where the financial markets are efficient.

Hence, omitting structural breaks from an econometric test leads to wrong conclusions. Our results therefore also confirm the results of Hughes Hallett and Richter (2002, 2004) and Bai and Perron (1998). Furthermore, we also showed that crisis times in particular lead to excessive volatile behaviour.

This behaviour is, of course, not compatible with the efficient market hypothesis. For the efficient market hypothesis to hold the distinction between “normal” and “not so normal” times does not exist. Hence, if one can prove the existence of only one period where the efficient market hypothesis does not hold the market cannot be efficient.

As a result, we have shown - by other means - that bond prices can deviate from the fundamental value (whatever that is) for a prolonged period of time as suggested by Ball (2009) and Barberis and Thaler (2003). Moreover, it can also be concluded that the efficient market assumptions simply do not hold as it was also shown by De Bondt et al. (2008) and Philips (1997).

**Table 17** German 2017 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.004452	0.000380	11.71449	0.0000
VARIANCE (-1)	1.003136	0.001126	891.2484	0.0000
VRESID	0.747491	0.010197	73.30565	0.0000
Variance equation				
C	2.05E-05	3.46E-06	5.913381	0.0000
RESID (-1)^2	1.523650	0.154555	9.858293	0.0000
GARCH (-1)	0.179062	0.021962	8.153322	0.0000
T-DIST. DOF	5.467712	0.741262	7.376221	0.0000
R-squared		0.981807	Mean dependent var	0.370093
Adjusted R-squared		0.981783	S.D. dependent var	0.344854
S.E. of regression		0.046546	Akaike info criterion	-4.521262
Sum squared resid		3.197751	Schwarz criterion	-4.496182
Log likelihood		3350.473	Hannan-Quinn criter.	-4.511912
Durbin-Watson stat		0.291933		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 22/11/13 Time: 16:41

Sample (adjusted): 31/07/2007 29/03/2013

Included observations: 1479 after adjustments

Convergence achieved after 69 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

All of the above are features of crises times where there is a large degree of uncertainty precisely because the full information set is typically not available. Hence, it is not really surprising that in crises times in particular the efficient market hypothesis does not hold.

## 6 Conclusion

In paper we used the Shiller volatility test to analyse different periods. We used a GARCH(1, 1) to estimate the excess volatility in two of the biggest financial asset markets, the US Treasuries and German Bunds, in a fast changing environment encompassing fixed periods/samples of high and low volatility.

By using daily data we had enough degrees of freedom to create subsamples where we could test each subsample individually. We then compared the subsample results with the sample results. The aim was to find out how the 2008 financial crisis may or may not have changed the efficiency of financial markets.



**Table 18** German 2017 Period 3 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.006665	0.001545	4.314692	0.0000
VARIANCE (-1)	1.005106	0.002573	390.6054	0.0000
VRESID	0.789827	0.018080	43.68481	0.0000
Variance equation				
C	0.000143	2.52E-05	5.682442	0.0000
RESID (-1)^2	1.379988	0.224340	6.151312	0.0000
GARCH (-1)	0.097725	0.034010	2.873390	0.0041
T-DIST. DOF	6.754192	1.745516	3.869454	0.0001
R-squared		0.976877	Mean dependent var	0.527228
Adjusted R-squared		0.976798	S.D. dependent var	0.397085
S.E. of regression		0.060484	Akaike info criterion	-3.654676
Sum squared resid		2.143797	Schwarz criterion	-3.602640
Log likelihood		1083.302	Hannan-Quinn criter.	-3.634402
Durbin-Watson stat		0.293590		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 26/11/13 Time: 11:08

Sample (adjusted): 31/07/2007 30/10/2009

Included observations: 589 after adjustments

Convergence achieved after 54 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

Looking at the overall sample results, it seems that the German market and the US market are fundamentally different: The US market seems to be efficient, whilst the German market is not. Looking at the subsamples we see that the periods where the German market is inefficient are exactly the same as in the US. Given that both financial markets show periods where they are not efficient, it turns out that both markets are actually inefficient in particular to the run up of a crisis and after the crisis. The results indicate that market participants over- and/or underreact to news especially in times of crises, but also before the crisis actually happens.

However, it should be pointed out that this does not mean market participants are “irrational”. As they are acting under uncertainty and do not have the full information set it is more appropriate speak of bounded rationality as opposed to unbounded rationality.

We could therefore confirm earlier results that financial markets are not as efficient as it is assumed especially in the neoclassical theory. The problem is while both neoclassical economics and the efficient market hypothesis are powerful benchmark tools; they do not reflect the real world.

**Table 19** German 2017 Period 4 GARCH

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.005924	0.000346	17.14174	0.0000
VARIANCE (-1)	0.975723	0.001524	640.2294	0.0000
VRESID	0.739618	0.012980	56.98042	0.0000
Variance equation				
C	7.84E-06	1.84E-06	4.272339	0.0000
RESID (-1)^2	1.321697	0.152443	8.670092	0.0000
GARCH (-1)	0.238089	0.027270	8.730977	0.0000
T-DIST. DOF	7.390157	1.720532	4.295274	0.0000
R-squared		0.982091	Mean dependent var	0.266101
Adjusted R-squared		0.982051	S.D. dependent var	0.257374
S.E. of regression		0.034482	Akaike info criterion	-5.170036
Sum squared resid		1.054640	Schwarz criterion	-5.132352
Log likelihood		2307.666	Hannan-Quinn criter.	-5.155632
Durbin-Watson stat		0.310827		

Dependent Variable: VARIANCE

Method: ML - ARCH (Marquardt) - Student's t distribution

Date: 26/11/13 Time: 11:08

Sample: 2/11/2009 29/03/2013

Included observations: 890

Convergence achieved after 35 iterations

Presample variance: backcast (parameter=0.7)

GARCH=C(4) + C(5)\*RESID(-1)^2 + C(6)\*GARCH(-1)

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