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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Quantitative easing and exuberance in government bond markets: Evidence from the ECB's expanded asset purchase program*

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Abstract

This paper examines the impact of Quantitative Easing (QE) in the Eurosystem on government bond yields and to what extent QE is causing government bond prices to deviate from their fundamental determinants. We apply a novel recursive estimation procedure developed by Phillips et al. (2015) to examine the existence of exuberant price behavior. The results show that government bond markets experienced exuberant price behavior in Euro Area countries following the announcement and implementation of several QE programs in 2014 and 2015. Especially the Public Sector Purchase Program (PSPP) contributed to exuberant price behavior as all countries experienced a divergence between observed and fundamental yield levels. However, almost no evidence of exuberance in government bond markets is found when QE policies are treated as drivers of government bond yields in addition to the traditional determinants. Given the influence of QE on government bond yields and prices, our findings imply that caution is warranted when this policy is eventually reversed.

Keywords: Government bond yields, asset price bubbles, monetary policy.
JEL classifications: G12, G15, E52.

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1. Introduction

Starting in September 2014 the European Central Bank (ECB) announced several Quantitative Easing (QE)[1] programs, also known as the Expanded Asset Purchase Program (EAPP)[2], in order to provide stimulus to the economy and to maintain price stability. These programs were implemented in an environment where policy rates were at their lower bound during a prolonged period of weak economic growth and low inflation in the Eurozone. Monthly purchases under the QE programs amount to €80 billion on average.[3] The sheer volume of these purchases raises the question to what extent the Eurosystem (ECB and National Central Banks) is distorting market prices and is causing overvaluations or bubbles.

There is abundant literature on financial bubbles for a wide range of asset classes. This literature distinguishes between intrinsic and speculative bubbles. Intrinsic bubbles depend on fundamental drivers of asset prices (Froot and Obstfeld, 1991). Speculative bubbles are driven by expectations that are not related to fundamental drivers (Diba and Grossman, 1988). Despite this vast literature and the various methodologies to detect bubbles (Gürkaynak, 2008; Homm & Breitung, 2012), there is not much literature on the influence of the ECB's purchasing programs on bubbles in government bond markets (and other asset classes). This paper aims to fill this gap.

This paper relates the literature on the determinants of government bond yields with the literature on statistical approaches to detect intrinsic or speculative bubbles in asset prices. We examine the impact of the EAPP on government bond yields and investigate whether government bonds experienced exuberant price behavior before and during the implementation of the EAPP. Our sample consists of 10 Euro Area countries over the period 2003-2016. Specifically, we focus on the Public Sector Purchase Program (PSPP), because

[1] The phrase Quantitative Easing was first applied to monetary policy in Japan in 2001. It was introduced to signal a shift in policy focus towards targeting quantity variables. With interest rates at the Zero Lower Bound, the Bank of Japan started purchasing government securities from the banking sector in order to boost the level of cash reserves the banks held in the system (Joyce et al. 2012).

2 The EAPP comprises: the third Covered Bond Purchase Program (CBPP3, since October 2014), the Asset-Backed Securities Purchase Program (ABSPP, since November 2014), the Public Sector Purchase Program (PSPP, since March 2015) and the Corporate Sector Purchase Program (CSPP, since June 2016)

[3] On 8 december 2016 the ECB announced a reduction in monthly purchases from €80 billion to €60 billion over the period March 2017 – December 2017.

it directly targets government bond markets and represents the bulk of the purchased volumes.

To analyze whether bond yields diverge substantially from their fundamental levels we utilize a novel methodology proposed by Phillips et al (2013; 2015). They introduce the Generalized Sup Augmented Dickey Fuller (GSADF) test, which is a recursive estimation procedure to distinguish a unit root process from a stochastic process with explosive (price) behavior. The authors show that their recursive estimation procedure is better able to distinguish bubbles in the S&P500 stock market than alternative testing procedures due to the presence of multiple bubbles. Hence they address the critique of Evans (1991) that conventional tests (i.e. standard unit root and cointegration tests) are not able to detect periodically collapsing bubbles. To the best of our knowledge, our study is the first paper that investigates the impact of the EAPP on government bond yields and prices with this novel approach. In addition, we introduce an alternative approach based on the Phillips and Perron (1988) unit root test that is also able to overcome the limitations of conventional tests in the presence of multiple bubbles.

Our results show that the QE programs significantly lowered government bond yield levels and have thus become an important driver of yields. Furthermore, all Euro Area countries experienced exuberant government bond prices in 2014 and 2015 during the EAPP. However, we find almost no evidence of exuberant government bond prices when QE programs are used directly as a fundamental driver to explain bond yields. These findings are indicative of an intrinsic bubble that is well explained by this new driver. The strong influence of the Eurosystem on government bond markets is not unexpected as these rates are targeted directly in order to pursue expansionary monetary policy goals. Within this context, the two test procedures used in this study may serve to monitor price exuberance in these markets closely.

This research has important implications for monetary policy. The large purchases have made the Eurosystem an important player on the government bond market. If government bond prices deviate substantially from their fundamental drivers due to central banks' bond purchases, the way monetary policy is communicated and normalized in the future may influence the pace and extent to which government bond prices reverse to their fundamental levels. The findings of this paper are also relevant for government debt policies, since they show to what extent monetary policy can affect the funding costs of government debt. Furthermore, a low interest rate environment also affects other areas of the economy such as households' saving behavior, pension funds' liabilities and housing markets.

The remainder of the paper is organized as follows. Section 2 contains a review of the literature on fundamental drivers of government bond yield (and spreads) and papers that apply the GSADF procedure to several asset classes. Section 3 outlines the data and the methodology. The empirical results are presented in section 4. Finally, section 5 concludes.

2. Literature review

2.1 Fundamental drivers of government bond yields

A lot of research has been conducted on the fundamental drivers of government bond yields and spreads. This strand of literature is important for this study in order to select relevant determinants for calculating fundamental levels of government bond yields. Selecting relevant fundamental drivers is not trivial. Maltriz (2012) conclude that there is no consensus yet about key determinants of government bond yields. Also De Haan et al. (2014) argue that bond yield model outcomes are strongly affected by modelling choices, especially the selection of variables and samples.

Most papers use panel data to investigate a set of countries in a chosen time period. However, a wide range of estimation procedures are used to establish a relationship between government bond yield (or spreads) and fundamental drivers. For example, the Pooled Mean Group (PMG) estimator (e.g. Poghosyan, 2014), the Common Correlated Effect Estimator and Panel Error Correction Models (Alfonso and Rault, 2015), Bayesian Moving Average models (Maltritz, 2012), Time Varying Coefficient approach (Bernoth & Erdogan, 2012), Panel Cointegration models (Bernoth & Erdogan, 2012, Constantini et al., 2014) and the fixed effects estimator (De Haan et al., 2014).

Despite the lack of consensus on the determinants of government bond yields and the diversity in model estimation approaches, there is some overlap in significant determinants across papers. Fiscal and trade-related variables such as the debt-to-GDP ratio and current account ratio appear to be important drivers in many studies (Afonso & Rault; 2015, Bernoth & Erdogan, 2012; Costantini et al., 2014; Georgoutsos and Migiakis, 2013; Maltritz, 2012; Poghosyan, 2014; Rivero and Morales-Zumaquero, 2015).Macroeconomic variables such as the real GDP growth and inflation are also significant fundamental drivers (Afonso and Rault, 2015; Poghosyan, 2014; Costantini et al. 2014). Some papers also include financial variables such as a proxy for the risk free rate or short term interest rate and stress and volatility on financial markets (De Haan et al, 2014; Poghosyan, 2014).

Complementary to fiscal, macroeconomic and financial market variables several studies distinguish between the period before and after the sovereign debt crisis to account for a structural change in the relationship between government bond yields and determinants (Bernoth et al., 2012; Giordano et al., 2013; Beirne and Fratzscher, 2013; De Haan et al., 2014). The sovereign debt crisis started at the end of 2009, when it became clear that fiscal policy in Greece was not sustainable. Empirical studies often use January 2010 as the beginning date of the sovereign debt crisis (De Haan et al., 2014).

Some studies emphasize that the relationship between government bond yields and fundamental drivers depends on the selected sample of countries. For example, Costantini et al. (2014) analyze government bond yield spreads in 9 EMU countries over the period 2001-2011 with a panel cointegration approach. The expected government debt-to-GDP differentials, cumulated inflation differentials, bid-ask spreads and government balance to GDP differentials appear to be drivers of government bond yield spreads.

Recent papers examine the impact of the Eurosystem's EAPP program on asset prices and the main transmission channels. The results of these papers indicate that QE has become an important price driver in several asset classes (especially the government bond market). In an event study, Altavilla et al. (2015) find that the EAPP has substantially lowered government bond yields. For government bonds with a 10-year maturity, the yield decline is estimated at around 30-50 basis points (depending on the window size that is used). Overall they find that the effects of asset purchases are not limited to the targeted assets nor to times of financial market stress. Georgiadis and Gräb (2016) focus on global financial markets and estimate the announcement effects of the asset purchase programs on the euro exchange rate, global equity prices and bond yields. They use daily data from 1 January 2007 to 31 January 2015 and a sample of the Euro Area's 39 major trading partners. Their results show a depreciation of the euro against other currencies, a boost in equity prices worldwide and a (limited) decline in global sovereign bond yields.

2.2 Applications of the GSADF procedure to identify bubbles

Homm and Breitung (2012) compare alternative tests for speculative bubbles in stock markets. The approach used in Phillips et al. (2011) is found to be the most powerful in detecting bubbles. This methodology relies on the sup ADF (SADF) test in order to investigate the presence of a bubble and is based on a sequence of forward recursive right-tailed ADF unit root tests.

Phillips et al. (2013, 2015) extend the SADF test by developing the GSADF test based on a more flexible recursive estimation procedure to distinguish a unit root process from a stochastic process with explosive behavior. The authors examine S&P500 stock market data over the period 1871-2010 and identify all the well-known historical episodes of stock market bubbles over this period, whereas other testing procedures that they apply seem to be more conservative and identify fewer periods of exuberant stock prices. The exact test procedure is further discussed in section 3.3.

Other studies use this novel methodology to examine asset bubbles and exuberant price behavior for different asset classes. These studies apply the GSADF on international housing prices (Engsted et al., 2016; Pavlidis et al., 2014; 2016), Real Estate Investment Trust (REIT) indices (Escobari and Jafarinejad, 2015), alternative energy stock prices (Bohl et al., 2015), oil prices (Caspi et al., 2015), the nominal Sterling-dollar exchange rate (Bettendorf and Chen, 2013), the Chinese RMB-dollar exchange rate (Jiang et al. 2015) and the Bitcoin market (Cheung et al. 2015).

3. Data & Methodology

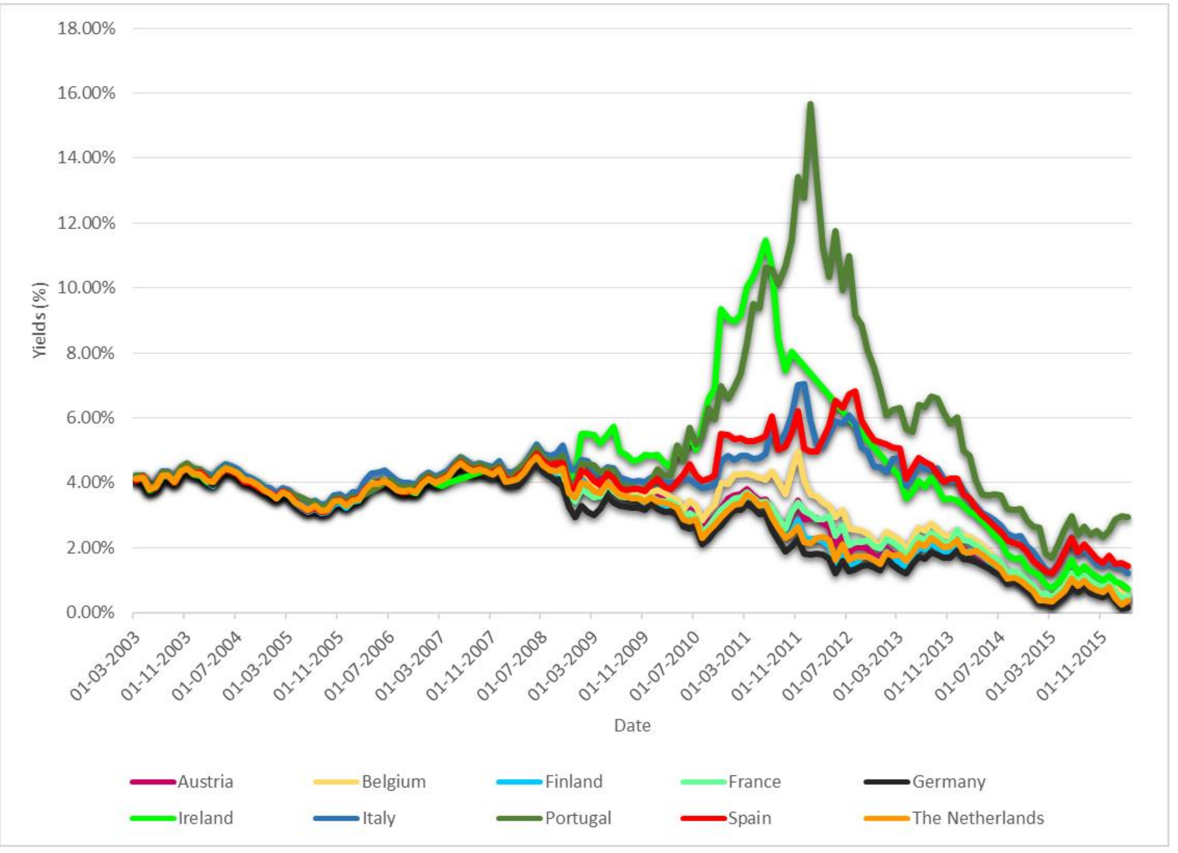
3.1 Data

In this paper we focus on 10 Euro Area countries: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Portugal, Spain and the Netherlands for the period 2003-2016. This section describes the data that is used to investigate exuberant price behavior in government bond prices through yield dynamics. To identify exuberant price behavior it is important to correct the time series for fundamental drivers of government bond yields since increases in government prices may be justified by increases in these drivers. All fundamental drivers used in this study are obtained from Bloomberg.

The nominal interest rates on government bond markets can be represented by the rates of "generic" government bonds. These generic rates are comprised of benchmark bonds, based on the bid side of the market, and are updated intraday. The government bond market is represented by the 10 year government bond yields.

Figure 1 shows the development of the government bond yields for these countries from March 2003 – March 2016. The government bond yield movements were similar until the sovereign debt crisis. Since approximately January 2010 yield differentials widened, especially for peripheral countries. Yields declined again in 2012 in a period of increased monetary policy easing. In general yields declined in all countries in 2014 following the announcement and implementation of the EAPP, but increased a little in the first half of 2015.

Figure 1: 10 year government bond yields over the period March 2003 – March 2016



The fundamental drivers of government bond yields used in this paper can be categorized into a fiscal variable (debt-to-GDP ratio), macroeconomic variables (real GDP growth and inflation), a variable related to trade (current account balance) and financial market variables (Euro OverNight Index Average (EONIA) and VIX index).[4]

The debt-to-GDP ratio is one of the most commonly used fundamental drivers in the literature on government bond yields and determinants. Debt-to-GDP is expected to be positively related to government bond yields. As government debt rises, government bond yields should go up due to perceived higher risk by investors that have government securities in their portfolio holdings (Poghosyan, 2014).

[4] De Haan et al. (2014) use Consensus forecast time series. Our study uses realizations of the macroeconomic and fiscal variables.

Inflation is expected to be positively related to government bond yields due to the relationship between nominal and real yields. Inflation is measured by the Harmonized Index of Consumer Prices (HICP).

When (real) GDP rises, the long term interest rate also rises. Interest rates are now very low, inter alia because real growth has declined relative to historic rates.

The current account ratio is related to a country's ability or inability to borrow abroad and therefore reflects investors' perception of default risk (Maltritz, 2012; De Grauwe and Ji, 2013). Current account deficits and net capital imports may be an indication of increased default risk and relate to lower government bond prices and higher yields.

The risk free rate (EONIA) is expected to be positively related to government bond yields. We follow De Haan et al. (2014) and assume that government bond yields consist of three components namely a risk free component, a risk premium and a residual term.[5] A higher risk free rate therefore translates into higher government bond yields.

The VIX index is also an often used financial market indicator. The VIX index is calculated by the Chicago Board Options Exchange (CBOE) and is a measure of the implied volatility of S&P500 index options. This variable reflects changes in global risk aversion (see e.g. Giordano et al., 2013; Beirne and Fratzscher, 2013; Aizenman et al., 2013; D'Agostino and Ehrmann, 2013; De Haan et al., 2014). A positive sign is expected since in more volatile markets the default risk of countries may increase which results in higher spreads and nominal yields.

All variables are on a monthly basis or interpolated to obtain observations on a monthly basis. Descriptive statistics per variable and country are shown in Table 1.

[5] This assumption is based on the preferred habitat theory of the yield curve (Modigliani and Shiller, 1973).

Table 1: Descriptive statistics per country

Country	Bond yield (in %)		Current account ratio (in % GDP)		Sovereign debt ratio (in % GDP)		Inflation (HICP, in %)		Real GDP growth (in %)		EONIA (in %)		VIX (in %)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
AT	2.77	1.31	2.67	0.96	78.84	6.45	0.16	0.48	0.99	2.14	1.51	1.41	19.52	8.37
BE	3.29	1.18	0.79	1.89	101.36	6.27	0.16	1.02	1.34	1.63	1.51	1.41	19.52	8.37
DE	2.78	1.29	5.52	1.67	70.77	6.10	0.12	0.41	1.19	2.53	1.51	1.41	19.52	8.37
ES	3.99	1.14	-4.15	3.80	61.54	23.07	0.16	0.82	1.26	2.52	1.51	1.41	19.52	8.37
FI	2.95	1.25	1.80	2.75	44.98	9.24	0.13	0.35	1.03	3.46	1.51	1.41	19.52	8.37
FR	3.09	1.14	-0.60	0.67	78.07	12.48	0.12	0.37	1.04	1.51	1.51	1.41	19.52	8.37
IE	4.39	2.07	-0.99	4.05	65.70	37.58	0.09	0.43	3.83	6.41	1.51	1.41	19.52	8.37
IT	4.04	1.10	-1.00	1.60	114.16	12.00	0.16	0.91	-0.16	2.20	1.51	1.41	19.52	8.37
NL	2.97	1.24	7.47	2.26	56.48	8.49	0.13	0.59	1.17	2.06	1.51	1.41	19.52	8.37
PT	5.11	2.52	-6.66	4.56	91.49	28.29	0.14	0.56	0.01	2.14	1.51	1.41	19.52	8.37

Note: Table 1 provides the mean and standard deviation for the 10 year government bond yield, current account ratio, debt-to-GDP ratio, inflation measure, real GDP growth, EONIA and VIX index for 10 Euro Area countries over the period March 2003 – March 2016. The EONIA and VIX index are common factors for all countries. The descriptive statistics are based on 157 observations per country except for Austria where 112 observations are used.

3.2 Fundamental drivers of Government Bond yields

We use several model specifications to calculate estimated yields based on fundamental drivers. This is essential input to measure a bubble in bond prices. The following panel data model is used:

$$BY_{it} = \beta_1 CA_{it} + \beta_2 DR_{it} + \beta_3 rf_t + \beta_4 rGDPg_{it} + \beta_5 I_{it} + \beta_6 VIX_t + \tau_t + \alpha_i + \varepsilon_{it} \quad (1)$$

where BY_{it} represents the government bond yield for each country *i* in time period *t*, CA_{it} is the current account ratio, DR_{it} is the debt-to-GDP ratio, rf_t is the EONIA as the risk free rate, $rGDPg_{it}$ is the real GDP growth, I_{it} represents inflation, VIX_t is the volatility index, τ_t are time fixed effects, α_i represents the country specific unobserved heterogeneity and ε_{it} is the error term that is assumed to be a white noise process $\varepsilon_{it} \sim N(0,\sigma^2)$.

To capture the announcement and implementation effects of the PSPP we include a time response function in equation (1).[6] The response function is obtained by using a set of dummy variables that represent time periods.

$$BY_{it} = \beta_1 CA_{it} + \beta_2 D_{it} + \beta_3 rf_t + \beta_4 rGDPg_{it} + \beta_5 I_{it} + \beta_6 VIX_t + \sum_{k=1}^{s} \beta_k Response_{kt} + \tau_t + \alpha_i + \varepsilon_{it} \quad (2)$$

where $Response_{kt}$ is the purchase program announcement variable that has been in effect for period *k* at time *t*, where each period consists of two consecutive months and the last dummy variable of the response function represents several months until the end of the time window. The response function is based on a chosen set of *s* dummy variables. The response function based on the PSPP is expected to show a negative effect on the government bond yields (Altavilla et al., 2015). Based on this specification we can test for announcement effects and examine the dynamics of the response to PSPP in more detail.

[6] A similar time response function is used by Wolfers (2006) and Bos et al. (2013) to capture policy effects in a panel data model. Both studies define the time response function based on two consecutive time periods.

Several robustness checks are applied. Equation (1) is extended with a dummy variable that captures the effect of the sovereign debt crisis (since January 2010) and with interaction terms between the macroeconomic variables and the sovereign debt crisis variable. We also use a specification where we define a time response function in equation (2) based on the announcement of the CBPP3 and ABSPP in September 2014.

3.3 Identifying Asset Bubbles: the GSADF and GSPP procedure

In the previous section a model is established to examine the determinants of government bond yields. With this model a fundamental level of yields can be calculated to correct the observed yield levels for fundamental behavior. Since there is an inverse relationship between government bond prices and yields, inverse yields can be used a proxy for price movements.

We examine the ratio between fundamental yield levels and the observed yield levels (*BY*/BY*), where fundamental yield levels and observed yield levels are represented by BY^* and BY, respectively. If the realized yields are perfectly described by a fundamental model (without noise), the ratio is constant and always equals 1. However, if actual yields decrease (i.e. prices increase) at a faster pace than the fundamental yields (or prices), the ratio increases.[7] The GSADF procedure developed by Philips et al (2013; 2015) examines to which extent the corrected time series for fundamentals exhibits explosive behavior.[8]

The GSADF procedure to identify explosive behavior in asset prices is based on the Augmented Dickey-Fuller (ADF) unit root test. Where the standard ADF test assumes that a time series contains a unit root or is stationary, the GSADF test assumes that the time series contains a unit root (null hypothesis) or that the time series exhibits explosive behavior (alternative hypothesis). Furthermore, the GSADF procedure applies the ADF test recursively by dividing the time window in smaller expanding time intervals.

The Augmented Dickey-Fuller test regression is:

[7] A drawback of this measure is that it may pose an identification problem if the fundamental yield level (BY^*) and the observed yield levels are of the opposite sign. In particular, detection of bubbles becomes difficult in the situation with negative observed yields and a positive level of fundamental yields. Our time series with observed yields only contain positive levels.

[8] De Haan et al. (2014) conclude that it is almost impossible to determine the exact extent of alignment between government bond yields and fundamental drivers due to model uncertainty. However, an appealing element of the GSADF test is that it examines explosive price behavior for a series corrected for fundamental drivers. Hence, the pace at which the ratio rises matters more for detecting bubbles than the exact (structural) level of the ratio.

$$\Delta y_t = \alpha_{r_1,r_2} + \boldsymbol{\pi}_{r_1,r_2} y_{t-1} + \sum_{i=1}^{k} \psi_{r_1,r_2}^{i} \Delta y_{t-i} + \gamma T + u_t, \tag{3}$$

where Δy_t is the corrected asset price in first differences ($y_t = BY^*/BY$), r_1 and r_2 are fractions of the time window to indicate the starting and ending point of a subsample, the terms Δy_{t-i} are lagged dependent variables to account for autocorrelation up to *k* terms, *T* is a deterministic trend and *u* represents the disturbance term that follows a white noise process $u_t \sim N(0,\sigma^2)$. The time series contains a unit root under the null hypothesis $H_0\colon \pi_{r_1,r_2} = 0$, while an explosive process (a characteristic of an asset price bubble) is assumed under the alternative hypothesis $H_1\colon \pi_{r_1,r_2} > 0$. The ADF test statistic is:

$$ADF_{r_1}^{r_2} = \frac{\hat{\pi}_{r_1,r_2}}{\text{s.e.}(\hat{\pi}_{r_1,r_2})} \tag{4}$$

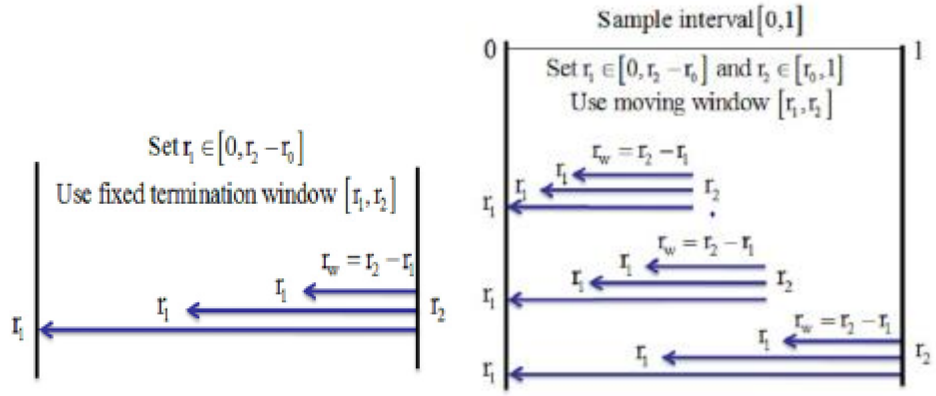
In the Backward Sup ADF (BSADF) test the end point of the sample is fixed at r_2 and the ADF test is performed on a backward expanding sample sequence, where the supremum (sup) value is calculated from the ADF statistics. The GSADF test is performed in multiple sub periods by varying both the starting and ending point r_1 and r_2. The GSADF test is therefore the sup value of the BSADF statistics. Compared to alternative existing testing procedures, the GSADF test is better able to detect explosive behavior if multiple bubbles exist due to the recursive estimation procedure with flexible starting and ending points (Phillips et al., 2015).

The test statistics of the BSADF and GSADF are:

$$BSADF_{r_2}(r_0) = \sup_{r_1 \in [0, r_2 - r_0]} \left\{ ADF_{r_1}^{r_2} \right\} \tag{5}$$

$$GSADF(r_0) = \sup_{r_2 \in [r_0, 1]} \left\{ BSADF_{r_2}(r_0) \right\} \tag{6}$$

Figure 2: Illustration of the BSADF and GSADF test



a) BSADF test b) GSADF test

Source: Phillips et al. (2015).

Phillips et al. (2015) recommend a date-stamping strategy based on the BSADF statistic. They show that the backward expanding sample sequence with fixed ending points is better for real-time monitoring purposes than a forward expanding sample sequence, because it provides more flexibility to detect multiple bubbles. The calculated BSADF statistics need to be compared with critical values to determine the timing of a bubble. The bubble starts if the BSADF statistic exceeds the critical value and ends if the BSADF is below the critical value. The timing of the asset bubbles is shown with the crossing time formulas:

$$\hat{r}_e = \inf_{r_2 \in [r_0, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) > scv_{r_2}^{\beta_T} \right\} \tag{7}$$

$$\hat{r}_f = \inf_{r_2 \in [\hat{r}_e, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) < scv_{r_2}^{\beta_T} \right\} \tag{8}$$

where $scv_{r_2}^{\beta_T}$ is the $100(1-\beta_T)\%$ critical value of the sup ADF statistic based on $[Tr_2]$ observations.

The implementation of the recursive testing procedure also requires the limit distributions of the BSADF and GSADF test statistics (see Phillips et al. 2013; 2015). These distributions are non-standard and depend on the minimum window size. Therefore, critical values have to be obtained through Monte Carlo simulations. We calculate the finite sample critical values by generating 2,000 random walk processes with ~ *N(0,1)* errors.

In addition to the GSADF test, we introduce the Generalized Sup Phillips-Perron test (GSPP) by using the same procedure as the GSADF but with the Phillips-Perron (PP) test instead of the ADF test. Phillips and Perron (1988) present an alternative method to deal with possible autocorrelation in the error term. While lagged dependent variables are included in the Augmented Dickey-Fuller test to account for autocorrelation, Phillips and Perron (1988) adjust the Dickey-Fuller statistics to deal with autocorrelation. The adjustments to the test statistics are based on corrections similar to Newey-West (HAC) standard errors. The PP test applies the same test regression as the original Dickey-Fuller test where no lagged dependent variables are included:

$$\Delta y_t = \alpha_{r_1,r_2} + \rho_{r_1,r_2} y_{t-1} + \gamma T + u_t \qquad (9)$$

Therefore, equation (9) replaces equation (3) in the GSADF procedure to identify bubbles. An advantage of the PP test over the ADF test is that the PP test is robust to a general form of autocorrelation in the error term of the test regression. Therefore, it is not necessary to specify a lag length for the regression of the PP test. The relative performance of the conventional ADF test and the PP test have been examined in several studies. The ADF test seems to perform better in smaller samples, if adequate adjustments are made to account for autocorrelation (Davidson & MacKinnon, 2004). [9] Choi and Chung (1995) use a simulation study and find that especially with low frequency data the PP test is more powerful than the ADF test.

[9] Optimal lag levels can also be determined based on the Akaike Information Criterion (AIC) and the Schwarz Bayesian Information Criterion (SBIC). These measures make a trade-off between goodness-of-fit and the number of regressors included in the regression. The SBIC contains a larger penalty for the inclusion of additional regressors. Since the GSADF is a recursive estimation procedure, the optimal lag may also differ in subsamples within the whole period. Determining the optimal lag length for each subsample increases the time to perform computations substantially and is out of scope of this paper. Alternatively the optimal lag length can be based on a regression performed for the whole period. Nevertheless, optimal levels for the whole sample may not be representative for subsamples. Computed lag levels are also country specific and range between 0 and 10 (if restricted to this value as max) based on the SBIC measure. For consistency reasons we use one lag for our main results and no lags for the sensitivity analysis for all countries.

4. Results

4.1 Fundamental Drivers of Government Bond Yields

Table 2 provides an overview of the results to examine the fundamental drivers of government bond yields. In the basic model specification (column 1) the current account ratio, the debt-to-GDP ratio, the risk free rate, inflation, real GDP growth and the VIX index are used as explanatory variables in an OLS estimation procedure. Only the current account ratio, the debt-to-GDP ratio, the risk free rate and real GDP growth are statistically significant at the 1% level. All variables have the expected signs. In column 2, the current account ratio becomes insignificant when accounting for fixed effects.

Column 3 accounts for the sovereign debt crisis. This variable is insignificant and has a minor effect on the slope coefficients of other variables. However, the specification in column 3 allows only for a shift in the level of government bond yields. It does not account for the possibility that the relationship between government bond yields and their drivers might have structurally changed after the sovereign debt crisis. This structural change can be modelled with interaction terms between variables and the sovereign debt crisis dummy variable (column 4). Several F-tests are performed to examine the joint significance of the sovereign debt crisis dummy variable and interactions with the macroeconomic variables. An F-test that is performed on the sovereign debt crisis dummy variable and all the interaction terms simultaneously shows that they are jointly significant at the 1% level (F-value of 55.0). When performing F-tests on the sovereign debt crisis dummy variable and its interaction with macroeconomic variables separately, the crisis dummy and interaction with the current account ratio, the debt-to-GDP ratio, real GDP growth and inflation are significant at the 1% level (F-values of 135.1, 7.6, 12.0, and 7.8, respectively). Both the current account ratio and the debt-to-GDP variable change to a negative sign after January 2010.[10] The significance of the interaction terms and changes in slope indicate a structural change in the relationship between government bond yields and their fundamental drivers.

[10] Changes in the sign of slope coefficients may also be due to endogenous explanatory variables as a consequence of reverse causality (or omitted variable bias). For example, while higher yields are associated with higher debt-to-GDP ratios due to higher perceived risks, lower yields may lead to increased debt levels due to lower funding costs (i.e. negative slope coefficient). Endogeneity issues are out of scope of this paper (as usual in most studies on the determinants of government bond yields).

This is in line with the findings of Bernoth et al. (2012), Giordano et al. (2013), Beirne and Fratzscher (2013) and De Haan et al. (2014).

In column 5 (monthly) time effects are added to the specification in column 4. The results are similar. In column 6, time effects since the announcement of the PSPP are taken into account. These dummy variables capture the cumulative effect of yields since January 2015 relative to periods before the announcement and are individually and jointly significant at the 1% level.[11] The results show that the government bond yields have reached on average substantially lower levels in the periods since the announcement of PSPP. However, the cumulative effect becomes less negative over time (-2.316 to -1.677).[12] The interaction between the sovereign debt crisis dummy and the debt-to-GDP ratio becomes individually insignificant due to the inclusion of the time response function, but jointly significant at a 10% level with the sovereign debt crisis dummy variable (F-value of 2.4).[13]

In column 7 we use the announcement of the CBPP3 and ABSPP in September 2014 to define the response function. The most noticeable change compared to column 6 concerns the sovereign debt crisis dummy variable which becomes less significant at the 10% level. Overall the results with regard to the macroeconomic variables and the financial market indicators seem to be fairly robust between the model specifications in column 6 and 7. However, the main difference between specifications is that the decline in yields is already captured since September 2014. This is important as it shows that the announcement of QE already had a very strong impact on bond yields.

[11] An F-test is performed to conduct a slope homogeneity test with regard to this set of dummy variables. Under the null hypothesis the slope coefficients are equal to each other and the PSPP announcement effect may be represented by a single dummy variable (i.e. a shock in the government bond yield level leading to an absorbing state). The null hypothesis that all slope coefficients of the set of dummy variables since the PSPP announcement are equal to each other is rejected at the 1% significance level. The F-statistic is 9.7.

[12] An explanation for the mitigation of the monetary policy impact may be the political situation in Greece and stock market events in China in the same period leading to an upward pressure of yields.

[13] We also performed the analysis in Table 2 column 6 with Greece in the sample of countries (results are in the Appendix, Table 6). Greece was excluded in the main analysis since these government bonds are not eligible for purchase within the PSPP. The debt-to-GDP ratio becomes individually insignificant, but its interaction with the 2010 dummy variable is significant at the 1% level. Also the 2010 dummy variable becomes individually insignificant, but most interaction terms with macroeconomic variables remain statistically significant. Overall most estimation results are qualitatively similar.

Table 2: 10 year government bond yields and its determinants.

	Dependent variable: Yield 10 yr government bond						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Basic model	+ fixed effects	+ 2010 sovereign debt crisis dummy	+ 2010 sovereign debt crisis dummy and interaction macro-economic variables	+ time effects	+ PSPP response function.	+ CBPP3/ ABSPP response function
	OLS	LSDV	LSDV	LSDV	LSDV	LSDV	LSDV
CA	-0.092***	-0.018	-0.015	0.150***	0.151***	0.144***	0.141***
	(0.009)	(0.020)	(0.015)	(0.014)	(0.015)	(0.014)	(0.014)
DR	0.013***	0.027***	0.026***	0.009***	0.010***	0.012***	0.013***
	(0.002)	(0.005)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
rf	0.538***	0.727***	0.746***	0.602***	0.592***	0.448***	0.435***
	(0.040)	(0.045)	(0.070)	(0.072)	(0.069)	(0.052)	(0.048)
I	0.042	0.083	0.081	-0.023	0.095	0.068	0.066
	(0.099)	(0.105)	(0.105)	(0.059)	(0.082)	(0.069)	(0.069)
rGDPg	-0.096***	-0.162***	-0.166***	-0.130***	-0.125***	-0.081***	-0.081***
	(0.013)	(0.015)	(0.016)	(0.030)	(0.028)	(0.021)	(0.020)
VIX	0.014*	0.013	0.013	0.016**	0.019**	0.022***	0.019***
	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)
2010			0.086	1.133***	1.103***	0.560**	0.449*
			(0.203)	(0.309)	(0.304)	(0.258)	(0.244)
2010*CA				-0.302***	-0.300***	-0.264***	-0.250***
				(0.021)	(0.021)	(0.021)	(0.021)
2010*DR				-0.009***	-0.009***	-0.003	-0.001
				(0.002)	(0.002)	(0.002)	(0.002)
2010*I				0.130	0.134	0.112	0.070
				(0.144)	(0.142)	(0.095)	(0.091)
2010*rGDPg				-0.016	-0.022	-0.002	-0.003
				(0.040)	(0.039)	(0.030)	(0.028)
Response 1						-2.316***	-1.737***
						(0.158)	(0.116)
Response 2						-2.290***	-2.179***
						(0.206)	(0.176)
Response 3						-1.652***	-2.465***
						(0.216)	(0.151)
Response 4						-1.525***	-2.418***
						(0.178)	(0.205)
Response 5						-1.677***	-1.850***
						(0.159)	(0.126)
Fixed effects	No	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	No	No	No	No	Yes	Yes	Yes
N	1525	1525	1525	1525	1525	1525	1525
Adj. R-sq	0.314	0.448	0.448	0.582	0.584	0.662	0.693

Note: The determinants of the 10 year government bond yields are examined in this table for 10 Euro Area countries. Six determinants of yield in equation (1) are used in an Ordinary Least Squares (OLS) regression in column 1. Column 2 is based on equation (1) but accounts for country fixed effects with the Least Squares Dummy Variables (LSDV) estimator. The results in columns 3 and 4 are based on an extension of equation (1) with a dummy that reflects a structural change in the level of yields since January 2010 and interactions with the country specific macroeconomic variables. Column 5 extends the results in column 4 by adding monthly time effects in the model specification. Column 6 is based on a time response function with dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-4) and a dummy that captures the remaining part of the time effects after August 2015 (Response 5). Column 7 is similar to column 6, but uses the CBPP3/ABSPP announcement in September 2014 to define the time response function. Robust standard errors are reported in parentheses. All standard errors are clustered at the firm level. Constants were included in the regressions but are not reported. *, ** and *** indicate significance at 10%, 5% and 1%, respectively.

4.2 Explosive behavior in government bond prices

This section provides an overview of the main results for the GSADF and GSPP tests on government bond yields. The results are based on 2,000 simulations to obtain the distributions of the GSADF and BSADF critical. The recursive estimation procedure is based on a minimum of 36 observations and a drift term in the test regressions. We include one lag in the ADF test regression equation for all countries. Robust test statistics for autocorrelation in the GSPP procedure account for up to 10 lags. Table 3 provides an overview of the results based on the model specification in Table 2 column 5 to correct for the fundamental level of yields. According to the GSADF test, all countries experienced a statistically significant deviation between observed yields and the estimated yields based on fundamental drivers within the period 2003-2016. Specifically, the results provide evidence of exuberant bond prices in all countries with a confidence level of 99%, except for The Netherlands where the confidence level is 95%. We find similar results with regard to the GSPP test.

Table 3: GSADF and GSPP test procedure results

	GSADF statistic	GSPP statistic
AT	7.800***	9.257***
BE	8.886***	10.232***
DE	4.934***	5.977***
ES	4.614***	13.505***
FI	6.825***	7.019***
FR	6.186***	10.562***
IE	4.281***	5.496***
IT	3.489***	10.226***
NL	2.426**	1.766*
PT	3.252***	5.729***

Note: An overview of the GSADF statistic and GSPP statistic is provided per country. The model specification in Table 2 column 5 is used to correct for the fundamental level of yields. The critical GSADF values (also used for GSPP test) are dependent on the sample size and therefore equal for BE, DE, ES, FI, FR, IE, IT, NL and PT. The critical values for AT are different since AT has a lower sample size. The critical values for BE, DE, ES, FI, FR, IE, IT, NL and PT for confidence levels 90%, 95% and 99% are 1.653, 1.992 and 2.631, respectively. The critical values for AT for confidence levels 90%, 95% and 99% are 1.432, 1.763 and 2.388, respectively. *, ** and *** indicate significance at 10%, 5% and 1%, respectively.

As discussed in section 3.3 the BSADF date-stamping strategy is used to identify the sub-periods of exuberant price behavior. Figure 3 provides an overview of the results at different confidence levels and shows that all countries experienced evidence of exuberant price behavior in government bonds during 2014 and 2015. Germany, Finland and Austria experienced evidence of exuberant price behavior with a 90% and 95% confidence level in some periods between 2008-2012.[14] However, the exuberant price behavior only persisted for a short time period (one to three months). Five countries already experienced some signals of exuberant government bond price behavior one or several months before the announcement of the EAPP in September 2014 with the purchase of ABSs and covered bonds. During the EAPP in November 2014 yields deviated more (statistically) significantly from their fundamental levels, with six countries indicating exuberant bond prices with a confidence level of at least 99%. The announcement of the PSPP in January 2015 led to exuberant bond prices in two more countries reaching a confidence level of 99% (The Netherlands and Germany). However, even though observed yields continued to deviate significantly from their fundamental levels during the announcement and implementation of the purchase programs, the results show no evidence of exuberant price behavior after March/April 2015. The effect of the EAPP on explosive price behavior seems to be temporary in nature. An explanation for this result is that the GSADF bubble detection procedure is able to detect a substantial decline in yields and soaring bond prices, but is less able to continue signaling the existence of a bubble without explosive price behavior. In other words, the GSADF test identifies the build-up of a bubble, rather than its persistence. The results for the GSPP test procedure in Figure 4 show similar patterns as the GSADF test procedure in Figure 3. Most evidence of exuberant price behavior is observed between September 2014 and March 2015.[15]

For illustrative purposes we examine the results for Germany, Italy, Spain and The Netherlands in more detail in Figures 5 – 8. The BSADF critical values (99% confidence level, dotted line), BSADF test statistics (blue line), BSPP test statistics (dark orange line)

[14] To examine the influence of QE on yields it is important to correct yields for traditional fundamental drivers. For example, we analyzed yields for Germany without correcting for QE or fundamental drivers. Exuberant price behavior with a confidence level of 99% is observed in August 2010, May, July and August 2012 and from August 2014 – April 2015. The signals until January 2015 disappear after correcting yields for the traditional fundamental drivers.

[15] We also performed an analysis where we do not account for autocorrelation in the ADF test regression by including lagged dependent variables. In the main analysis we account for one lag in the test regression. The results based on an ADF test regression without lags for autocorrelation provides a similar pattern as in Figure 3 where one lag is used to account for autocorrelation (See Appendix Figure 9). Even though most signals of exuberant price behavior in government bonds overlap, some differences between the figures are still visible such as statistically significant signals that arise suddenly (e.g. for The Netherlands in February 2016) or disappear (e.g. for Finland July/ August 2012). Also changes in confidence levels are observed for overlapping signals between Figure 3 and 9 (e.g. for The Netherlands in February/ March 2015 from 99% confidence level in Figure 4 to 95% confidence level in Figure 10).

are shown at each point in time. Also the ratio between predicted yields and observed yields is shown. If the test statistics (blue or dark orange line) exceed the critical values (dotted line) the deviation of observed yields from fundamental levels becomes statistically significant at the 1% significance level (i.e. 99% confidence level). For these four countries the confidence levels of the price exuberance in government bond yields and prices were highest during the period January 2015- March 2015. Spain already experienced a confidence level higher than 99% during November and December 2014.

In general, the figures show that the ratio between predicted and observed yields remains quite stable around the value of 1 before 2014Q4. Thereafter the ratio soars compared to previous periods within the sample and is subject to larger volatility. Both tests have difficulties in detecting exuberant price behavior during periods of high volatility. Even though the ratio reaches high levels in 2016 for the four countries, only the GSPP testing procedure detects exuberant price behavior in February 2016 for The Netherlands, Germany and France with a confidence level of 99%, 90% and 95%, respectively.

Figure 3: Periods of exuberance in government bond prices and yields in Euro Area countries (Table 2, column 5, GSADF test)

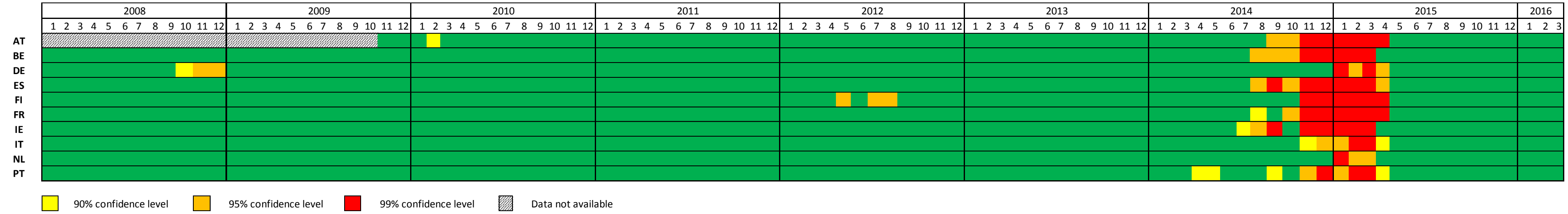


Figure 4: Periods of exuberance in government bond prices and yields in Euro Area countries (Table 2, column 5, GSPP test)

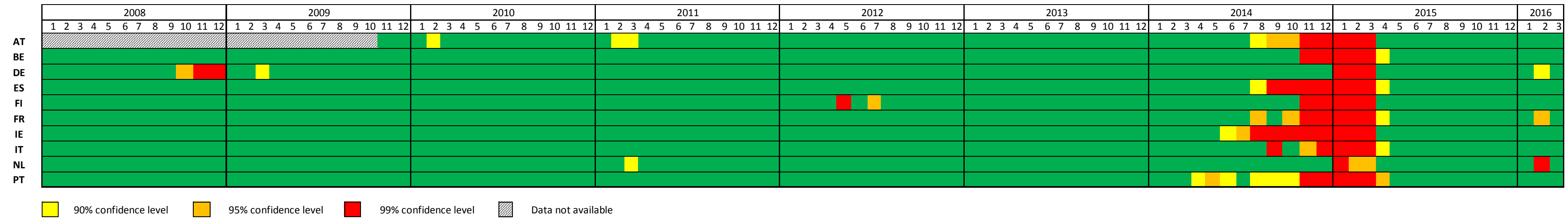
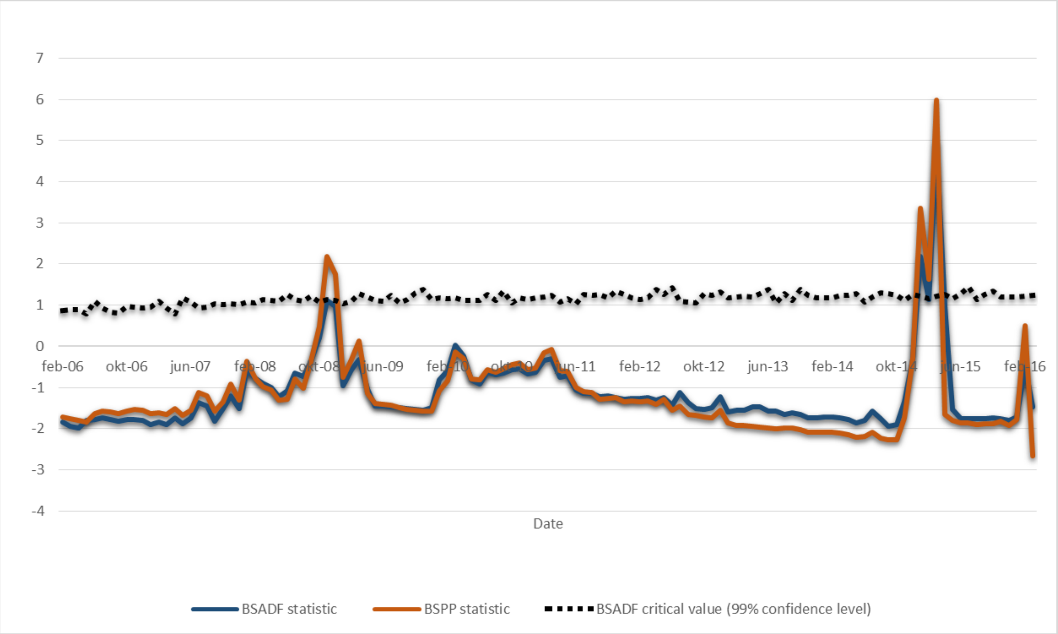


Figure 5: Germany - Date-stamping periods of exuberance in government bond prices

(specification Table 2, column 5)



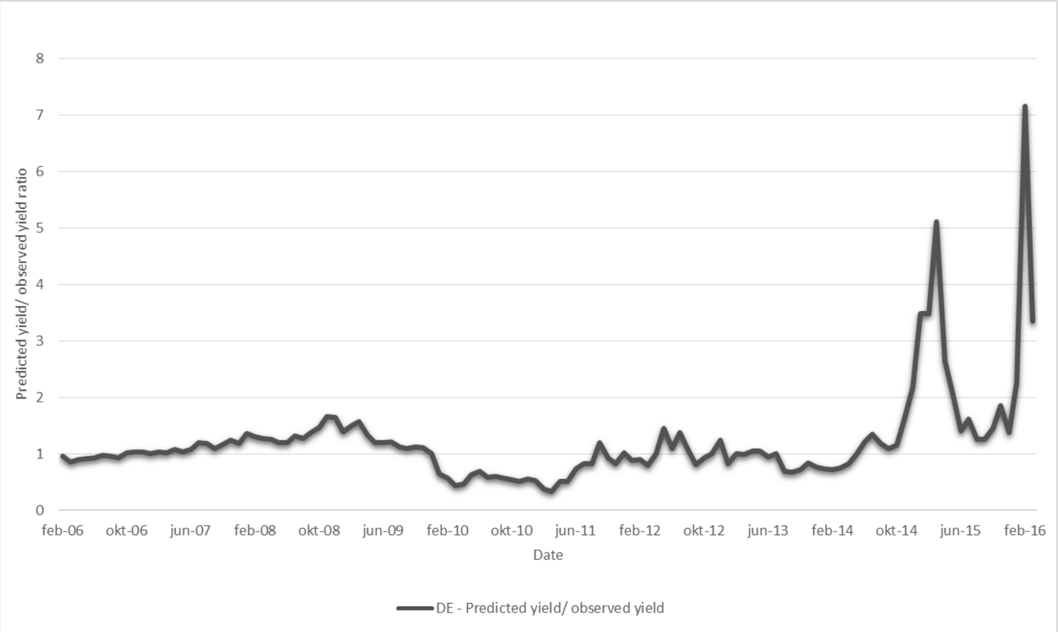


Figure 6: Italy - Date-stamping periods of exuberance in government bond prices

(specification Table 2, column 5)

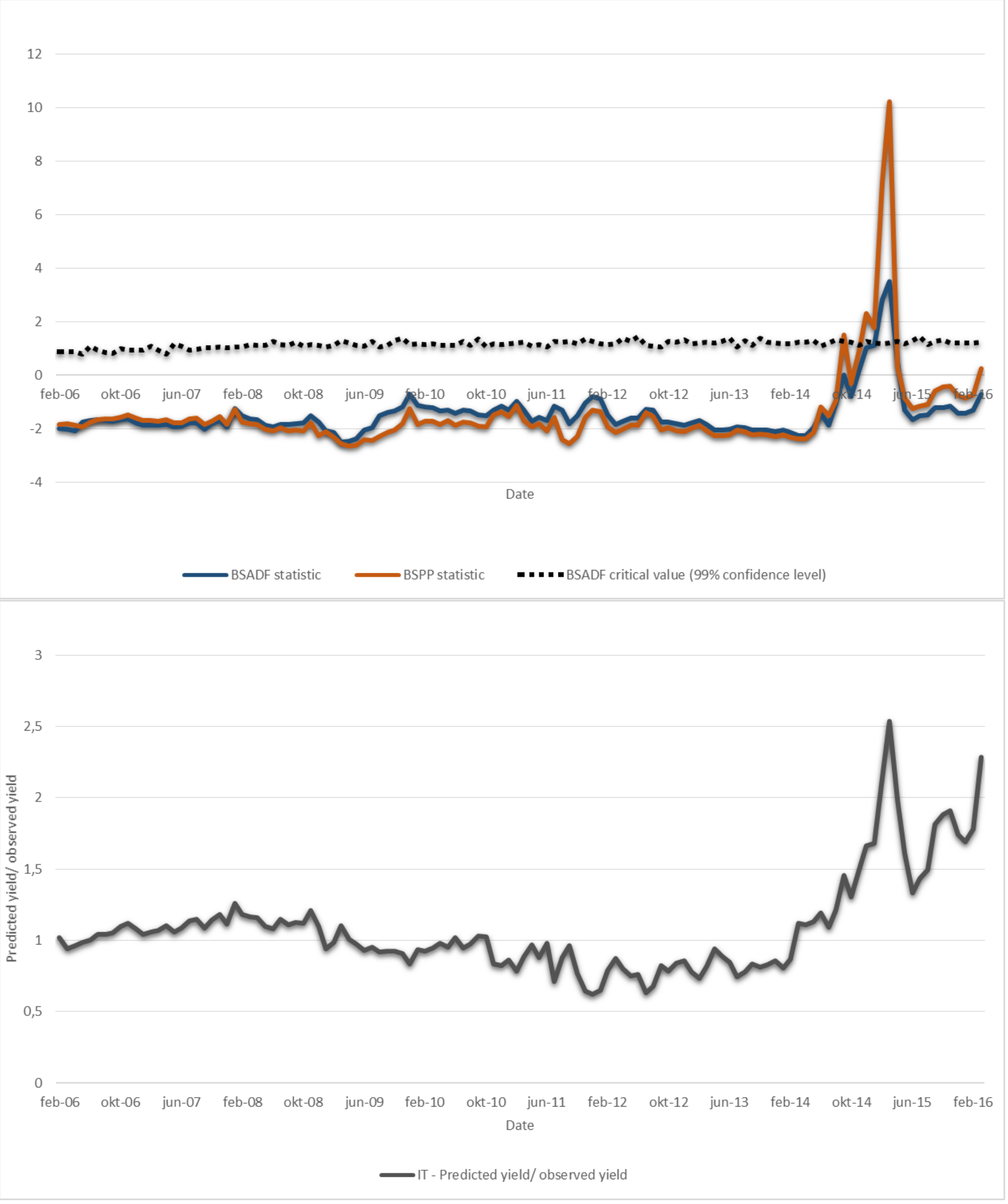
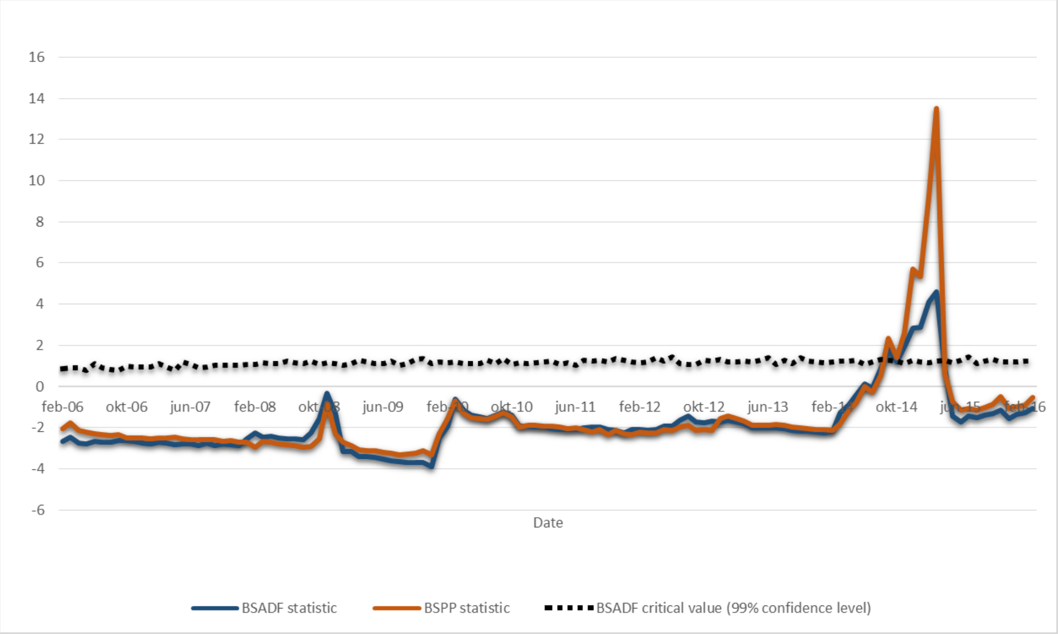


Figure 7: Spain - Date-stamping periods of exuberance in government bond prices
(specification Table 2, column 5)



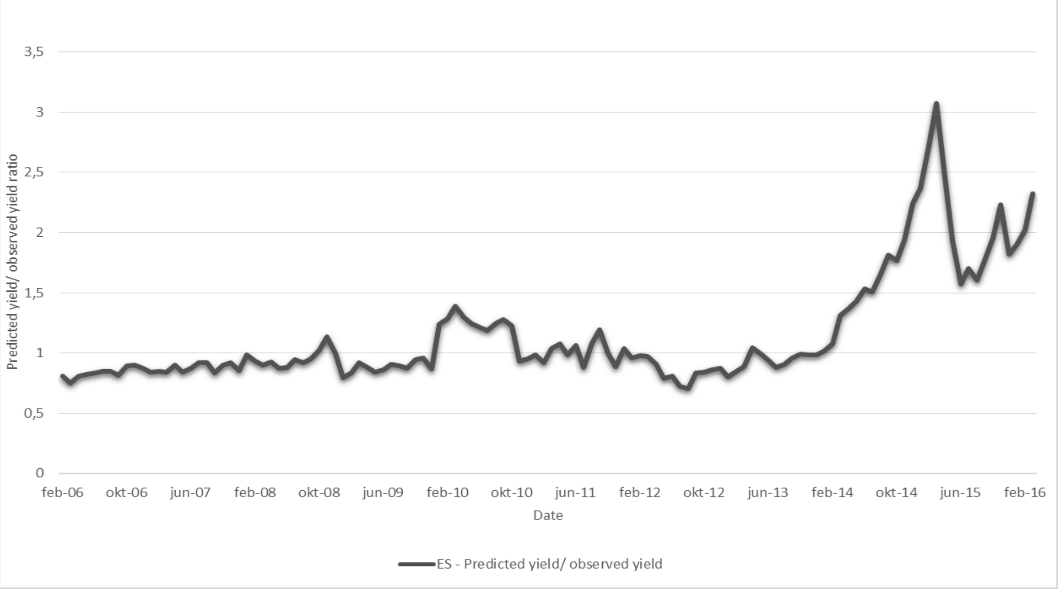
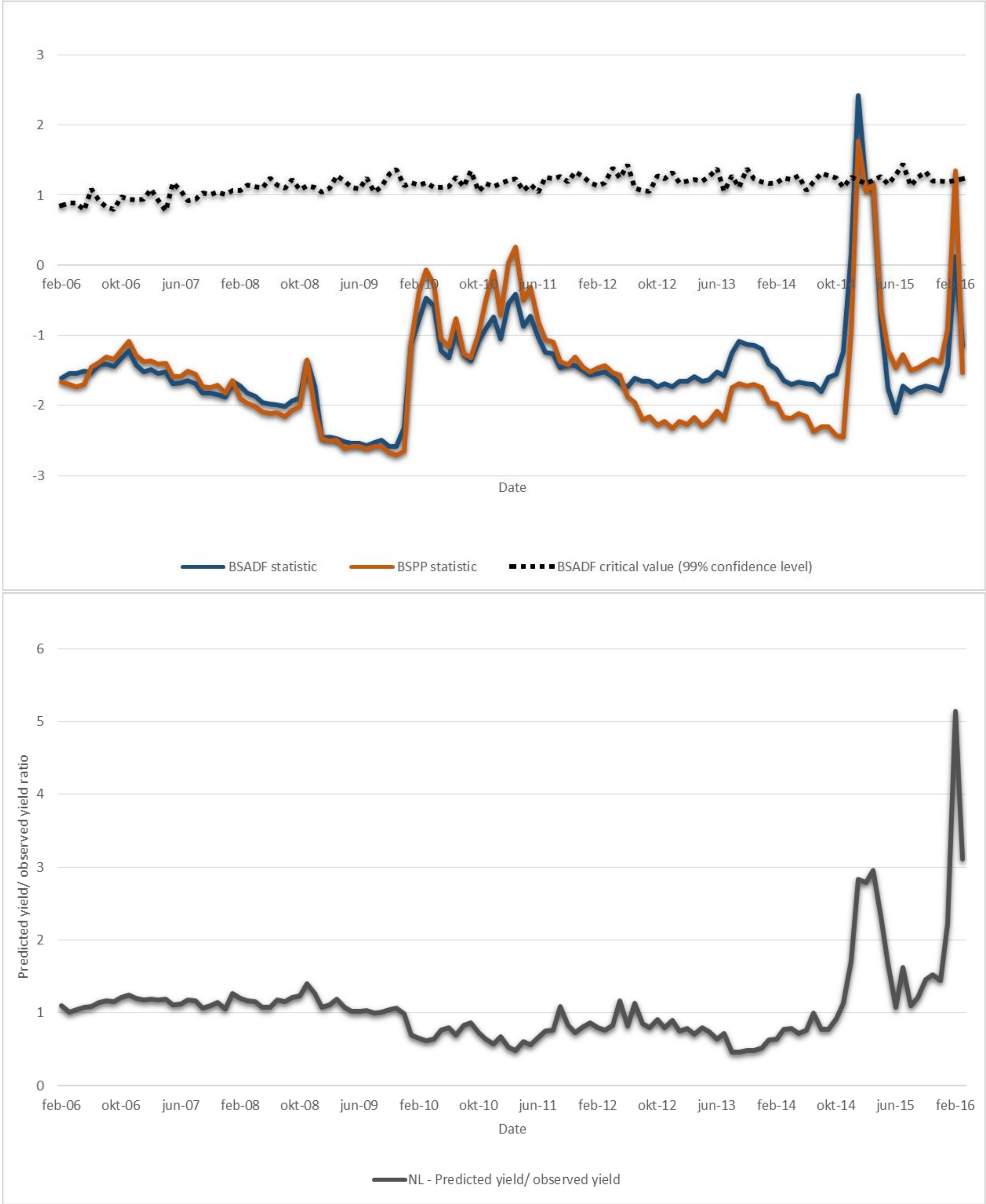


Figure 8: The Netherlands - Date-stamping periods of exuberance in government bond prices (specification Table 2, column 5)



4.3 Exuberant price behavior in government bonds: GSADF and GSPP results with the PSPP announcement date as fundamental driver

In this section the results are described based on equation (2) and the results in Table 2 column 6 to perform the GSADF and GSPP procedure. The announcement of the PSPP and subsequent time effects are taken into account to determine fundamental values of the 10 year government bond yields. Table 4 provides an overview of the GSADF and GSPP test procedure results. The number of observations of exuberant price behavior since the announcement of the PSPP is also presented for different confidence levels.

When using the PSPP response function as a fundamental driver of government bond yields, most countries no longer show evidence of exuberant price behavior after January 2015. Only Germany and Spain indicate exuberant price behavior with a 95% and 90% confidence level, respectively. This implies that the previously estimated response function, ceteris paribus on other fundamental drivers, captures the explosive behavior in bond yields well. That is, when corrected for announcement effects and the implementation of the PSPP there are almost no bubbles found in sovereign yields.

Table 4: GSADF and GSPP test procedure results

			Nr. of observations with exuberant price behavior after January 2015 for each confidence level (GSADF/ GSPP)		
	GSADF statistic	GSPP statistic	90%	95%	99%
AT	3.948***	5.705***	0/0	0/0	0/0
BE	5.102***	4.611***	0/0	0/0	0/0
DE	0.925	2.202**	1/0	1/0	0/0
ES	3.389***	8.168***	1/0	0/0	0/0
FI	3.317***	3.272***	0/0	0/0	0/0
FR	4.227***	5.658***	0/0	0/0	0/0
IE	3.509***	4.468***	0/0	0/0	0/0
IT	1.898*	4.438***	0/0	0/0	0/0
NL	1.807*	1.550	0/0	0/0	0/0
PT	1.578	2.796***	0/0	0/0	0/0

Note: An overview of the GSADF statistic and GSPP statistic is provided per country. Table 2 column 6 is used to determine the fundamental level of yields. The critical GSADF values (also used for GSPP test) are dependent on the sample size and therefore equal for BE, DE, ES, FI, FR, IE, IT, NL and PT. The critical values for AT are different since AT has a lower sample size. The critical values for BE, DE, ES, FI, FR, IE, IT, NL and PT for confidence levels 90%, 95% and 99% are 1.653, 1.992 and 2.631, respectively. The critical values for AT for confidence levels 90%, 95% and 99% are 1.432, 1.763 and 2.388, respectively. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. Also the number of observations with exuberant price behavior after January 2015 (announcement PSPP) is shown for different confidence levels. The number of observations between the GSADF and GSPP are distinguished by the / symbol.

4.4 Exuberant price behavior in government bonds: GSADF and GSPP results with the CBPP3/ABSPP announcement date as fundamental driver

Table 5 provides an overview of the results when equation (2) is used based on the announcement of the EAPP with the CBPP3 and ABSPP programs in September 2014 (Table 2, column 7). Clearly the time response function explains yield dynamics well in the first four months since the announcement in September 2014 as no observations with exuberant price behavior are found based on either the GSADF or the GSPP test. With the exception of the Netherlands, Germany and Portugal, most countries do not show exuberant price behavior in the period after the PSPP announcement in January 2015. This implies that the time response function based on the CBPP3/ABSPP announcement is not able to fully capture the yield dynamics in The Netherlands, Germany and Portugal after the PSPP announcement in January 2015. Overall, these results show only weak evidence of exuberant price behavior during the announcement and implementation of the EAPP, if the EAPP is used as a fundamental driver to explain yield dynamics.

Table 5: GSADF and GSPP test procedure results

			Nr. of observations with exuberant price behavior from September 2014 until December 2014 for each confidence level (GSADF/ GSPP)			Nr. of observations with exuberant price behavior since January 2015 for each confidence level (GSADF/ GSPP)		
	GSADF statistic	GSPP statistic	90%	95%	99%	90%	95%	99%
AT	0.460	0.516	0/0	0/0	0/0	0/0	0/0	0/0
BE	1.382	1.261	0/0	0/0/	0/0	0/0	0/0	0/0
DE	6.042***	5.525***	0/0	0/0	0/0	4/3	4/3	4/2
ES	1.662	2.130**	0/0	0/0	0/0	0/0	0/0	0/0
FI	0.871	3.156***	0/0	0/0	0/0	0/0	0/0	0/0
FR	1.145	1.660*	0/0	0/0	0/0	0/0	0/0	0/0
IE	2.284**	2.506**	0/0	0/0	0/0	0/0	0/0	0/0
IT	-0.005	0.842	0/0	0/0	0/0	0/0	0/0	0/0
NL	2.601**	1.252	0/0	0/0	0/0	3/3	3/3	3/1
PT	1.025	1.184	0/0	0/0	0/0	0/1	0/1	0/0

Note: An overview of the GSADF statistic and GSPP statistic is provided per country. Table 2 column 7 is used to determine the fundamental level of yields. The critical GSADF values (also used for GSPP test) are dependent on the sample size and therefore equal for BE, DE, ES, FI, FR, IE, IT, NL and PT. The critical values for AT are different since AT has a lower sample size. The critical values for BE, DE, ES, FI, FR, IE, IT, NL and PT for confidence levels 90%, 95% and 99% are 1.653, 1.992 and 2.631, respectively. The critical values for AT for confidence levels 90%, 95% and 99% are 1.432, 1.763 and 2.388, respectively. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. The number of observed exuberant price behavior since September 2014 (announcement CBPP3 and ABSPP) is shown for different confidence levels. Two periods are distinguished namely September 2014- December 2014 and the period since January 2015.The number of observations between the GSADF and GSPP are distinguished by the / symbol.

5. Conclusions

The Eurosystem launched an unprecedented expansion of monetary policy operations in September 2014 in order to get inflation back towards the desired target. This has made the Eurosystem an important participant in financial markets and has raised the question to which extent its operations have caused divergences between market prices and fundamental values. To identify such exuberance in government bond markets, we present two recursive estimation procedures (GSADF and GSPP test) as monitoring tools to examine and focus the discussion on 10 key Euro Area countries.

Our results show that the announcement and implementation of QE are important drivers of government bond yields as QE policies explain deviations of yields from their traditional fundamental values. This outcome is expected given the ECB's efforts to influence government bond markets with its' QE programs directly. Given the importance of the QE programs in explaining yield dynamics, our results may be indicative of an intrinsic bubble which can be explained by this new driver.

The large purchases have made the Eurosystem an important player on the government bond market. QE policies have raised bond prices relative to their traditional fundamental values. Therefore caution is warranted with regard to the specific timing and the design of monetary policy normalization in order to avoid adverse effects on financial markets and the real economy. A gradual winding down of central banks' activities (tapering) may seem the preferred strategy as large changes in purchasing volumes may adversely affect the stability of financial markets. Central bank communication regarding an eventual exit is also very important as our results show that announcement effects have a large impact on yields.

Future research is recommended in several areas. First, our research shows that exuberant price behavior can be examined with both test procedures presented in this paper. Nevertheless, an important limitation of both test procedures is that they are less able to signal the continued existence of a bubble after explosive price behavior disappears. In this context, more statistical evidence can help to define exuberance in government bond prices, in particular in terms of the minimum level and duration of the deviation between observed prices and fundamentals in order to classify as a bubble. Future research is also warranted with regard to the determinants of government bond yields. Correcting observed yield data for fundamental levels is a crucial step in this study and more research can be conducted on complementary fundamental drivers. For example, more direct measures of (unconventional) monetary policy can be used to disentangle the effects of the purchase programs from those of forward guidance on monetary policy and from other events on financial markets. Future research is also recommended with regard to expanding the GSADF and GSPP procedure to other asset classes and other countries that implemented QE to obtain a broader perspective on the effects of the QE programs on financial markets.

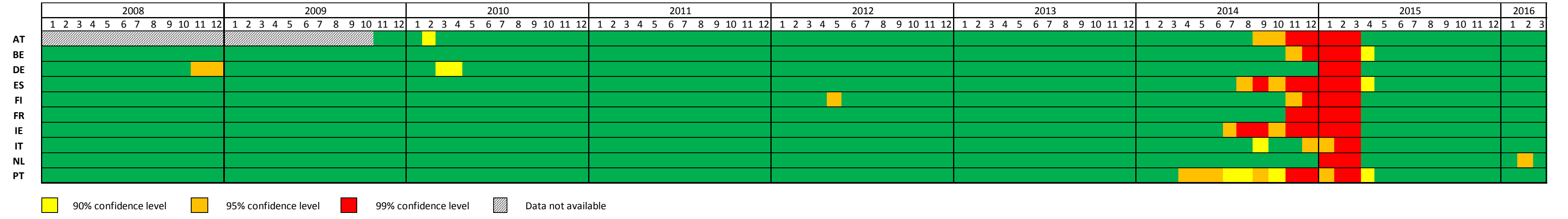
APPENDIX

Table 6: 10 year government bond yields and determinants when Greece is included in the sample of countries

	Dependent variable: 10 yr government bond yield
	(1)
	Greece added to the sample
	LSDV
CA	0.211***
	(0.029)
DR	0.0004
	(0.006)
rf	0.467***
	(0.060)
I	0.013
	(0.120)
rGDPg	-0.106***
	(0.029)
VIX	0.024**
	(0.009)
2010	0.002
	(0.400)
2010*CA	-0.358***
	(0.039)
2010*DR	0.010***
	(0.004)
2010*I	0.045
	(0.175)
2010*rGDPg	-0.145**
	(0.066)
Response 1	-2.267***
	(0.241)
Response 2	-1.989***
	(0.278)
Response 3	-1.276***
	(0.296)
Response 4	-1.111***
	(0.273)
Response 5	-1.275***
	(0.222)
Fixed effects	Yes
Time effects	Yes
N	1634
Adj. R-sq	0.657

Note: In column 1 Greece is added to the basic sample of countries. The analysis is based in the Least Squares Dummy Variables (LSDV) estimator to account for country fixed effects. The response function is based on the PSPP announcement date. Robust standard errors are reported in parentheses. All standard errors are clustered at the firm level. Constants were included in the regressions but are not reported. *, ** and *** indicate significance at 10%, 5% and 1%, respectively.

Figure 9: Periods of exuberance in government bond prices and yields in Euro Area countries (Table 2, column 6, GSADF test without lags in the ADF test regression)



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