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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 Stock Markets: Evidence from the euro area *

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Abstract

In response to a prolonged period of low inflation, the European Central Bank (ECB) introduced Quantitative Easing (QE) in an attempt to steer inflation to its target of below, but close to, 2% in the medium term. This paper examines whether QE contributes to exuberance in euro area stock markets by using recent advances in bubble detection techniques (the GSADF-test). We do so by linking price developments in 10 euro area stock markets to a series of country specific macro fundamentals and QE. The results indicate that periods of QE coincide with exuberant investor behaviour, even after controlling for improving macro fundamentals.

JEL codes: G12; G15; E52; E58

Key Words: exuberance, asset price bubbles, unconventional monetary policy, quantitative easing

1 Introduction

In response to a prolonged period of low inflation in recent years, central banks introduced unconventional monetary policy measures (UMP) in an attempt to steer inflation to target. As a result, the US Federal Reserve, European Central Bank, Bank of Japan and Bank of England bought over $13 trillion worth of financial assets over the past decade, representing between 18 and 102% of their respective total GDP.[1] While these measures - known as Quantitative Easing (QE) - are generally deemed a success, they are not without controversy. Implementing QE has led to concerns, especially about the risk of creating asset pricing bubbles.[2] The bulk of this critique focuses on the nature of the asset purchases. By directly intervening in financial markets

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[1] This reflects the combined Federal Reserve, ECB, Bank of Japan and Bank of England purchases till July 2019. The total central bank asset purchases account for 18.1%, 40%, 102.3% and 22.8% of GDP for the Fed, ECB, BOJ and BoE respectively.

[2] See for instance Knot (2015, 2019) and Weidmann (2015). They mention the risk of asset pricing bubbles as a downside to the ultra-loose monetary policy conducted by the ECB.

these purchases do not only lower the expected return on targeted safe assets, but also fuel a search for yield, pushing investors into other asset classes with a higher expected return. This phenomenon is well described in the academic literature and is known as the portfolio rebalancing channel of QE (see e.g. Albertazzi et al., 2018; Koijen et al., 2017). Although a lower price of risk is one of the intended effects of QE, it also increases the probability of overheating and inflating asset price bubbles, i.e. cause asset prices that no longer reflect their fundamental value (see e.g. Chen et al., 2016; De Haan and Van den End, 2018). Asset bubbles can have detrimental effects on the financial system. At the root-cause of the credit crisis were asset valuations that were misaligned with the true risks of the asset (see Diamond and Rajan, 2009). Therefore, monitoring the buildup of new asset bubbles is key to maintaining a healthy financial system. Moreover, newly formed bubbles can give rise to future systemic financial crises when left unchecked by regulators (see e.g. Brunnermeier et al., 2019).

While there is a burgeoning literature on the effect of QE measures in the euro area, little is known about the effect of QE on the potential of bubble formation financial assets. Leading studies primarily focus on the effect of UMP measures by analyzing the response of financial market assets to policy announcements. From this literature, we know that UMP measures have been effective in lowering yields on targeted assets, such as US bonds (Krishnamurthy and Vissing-Jorgensen, 2011; Gagnon et al., 2011), and led to higher stock prices in the US (Rosa (2012)), the euro area (Haitsma et al., 2016) and emerging markets (Tillmann, 2016; Chen et al., 2016; Fratzscher et al., 2017). However, there have been no studies that establish whether QE coincides with the formation of asset bubbles, i.e. valuations that deviate from their fundamental value, in the euro area stock markets. This gap in the literature relates to challenges in empirically detecting the buildup in asset pricing bubbles in stock markets.

We use recent advances in bubble detecting techniques to test whether periods of active QE-programmes coincide with exuberant behaviour on stock markets. We specifically look at stock markets as the search for yield makes risky assets (such as equities) more vulnerable for overvaluation.[3] In an environment with QE, risky assets become an attractive investment in comparison with the alternative of low, or even negative yielding safe assets. This mechanism drives investors into more risky assets, thereby artificially suppressing risk premia. In turn the mechanism might lead to valuations that lie above their fundamental value (i.e. do not represent their true value).

Our approach consists of two steps. *First*, we use a relatively new method to detect (statistical) exuberance introduced by Phillips et al. (2015).[4] The statistical test - known as the Generalized Sup Augmented Dickey Fuller (GSADF) - distinguishes between a unit root process and a stochastic process with explosive (price) behaviour (i.e. more than proportionally increasing over time). The GSADF test is a statistical measure that establishes when the dynamics of price increases follow an explosive pattern, i.e. it looks at rates of change and not at the price level as such.[5] We use the test to detect bubbles in their inflationary stage, as the asset price is explosive when a bubble is present (see Phillips et al., 2015). The method enables us to robustly test for the build up of a bubble (exuberance) in a time-series with multiple bubbles. This is important since conventional tests (i.e. standard unit root and cointegration tests) are not able to detect periodically collapsing bubbles, which are present in most time-series of asset prices

[3]Moreover, it is not only important to analyze the effect of monetary policy on directly targeted markets, but also the (side) effects on other financial markets.The Association for Financial Markets in Europe (AFME, 2015) points out that European equity markets played an important role in helping damaged economies to recover from the financial crisis. Companies in ‘peripheral’ European countries raised more than €30 billion during the first half of 2014.

[4]Asset pricing bubble, explosive behaviour and exuberance will be used interchangeably throughout the paper.

[5]This means that the method is less suitable to signal the continued existence of a bubble when it is no longer increasing.

(see Evans, 1991).

Second, we relate the buildup of a bubble to (macro) fundamentals that might drive the explosive increase in equity valuations. From basic finance theory we know that such key determinants of equity value consist of a firm's investment opportunities with an expected rate of return higher than the cost of capital (Fama, 1981). Against this background, we control for the changes in macro variables that reflect business conditions such as GDP, industrial production, unemployment, long-term interest rates, the slope of the yield curve, credit to the non-financial sector and the shadow short rate (SSR).[6,7] In addition, we use the Shiller P/E ratio to reflect equity valuations. By doing so, we relate the price of a stock index to its real average earnings over the past decade (see Campbell and Shiller (2005) and Santa-Clara and Valkanov (2003)). Thereby, we correct for the cyclical component in earnings yield.

We *first* hypothesize that there are periods of exuberant behaviour in euro area stock markets. We test for a unit root in the Shiller P/E ratio for 10 euro area equity markets with the GSADF statistic. The results indicate significant exuberance in the stock markets of Belgium, Finland, Ireland, Italy and The Netherlands during the implementation of QE, indicating that periods of QE coincide with exuberance.

Second, we hypothesize that QE increases the probability of exuberant investor behaviour in the euro area. We test this hypothesis by introducing a time response function for QE to our main model specifications. The results suggest that QE significantly contributes to exuberant behaviour in the euro area, especially around the announcement of QE (January 2015) and the start of the Extended Asset Purchase Programme (EAPP, March 2015).[8] However, the time response function also shows that the effect of QE is temporary. Besides the significant impact of QE on the probability of exuberance, we also find that higher GDP growth and a higher SSR contribute to a higher likelihood of (statistically) exuberant investors, though the relation with the shadow short rate seems to be driven by the crisis period (2008-2009) in our sample.

Our *third*, and final hypothesis, states that periods of exuberance have a tendency to persist. We test the hypothesis by introducing a dynamic probit model which allows us to test the persistence of asset pricing bubbles over time. The results indicate there is a high probability of exuberant price behaviour in future periods when exuberance exists in the current period. This finding is in line with literature describing persistence in equity returns (see Chou, 1988 and Campbell, 1990).

Against the backdrop of the restart of net asset purchases by the ECB in November 2019, our findings are relevant for two reasons. First, the announcement and implementation of new purchases requires increased vigilance and close monitoring of the side-effects on equity markets. Second, the results have implications for monetary policy normalization, in particular to avoid adverse effects on financial markets. As the announcement of QE in January 2015 led to exuberance in stock prices, it also asks for a careful communication strategy regarding the end of net asset purchases and phasing out the reinvestment of maturing bonds.

This paper contributes to the existing literature in several ways. *First*, we focus on equity markets in the euro area, whereas previous literature has only considered other jurisdictions.

[6]See for GDP Fama (1981); for industrial production Fama (1981); Humpe and Macmillan (2009); Chen et al. (1986); Cheung and Ng (1998); McMillan et al. (2001); for unemployment Asprem (1989); Boyd et al. (2005), for long term interest rates Rapach et al. (2005); for the slope of the yield curve Estrella and Hardouvelis (1991); Ang et al. (2006); for credit to the non-financial sector Jordà et al. (2013); Jordà et al. (2015) and Claus et al. (2018) for the shadow short rate.

[7]The shadow rate measures the stance of the monetary policy when the conventional monetary policy instrument (the policy rate) is at the zero lower bound (ZLB). In that way it tries to approximate the impact of QE on financial conditions, i.e. what the short rate would be when there is no QE.

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

Huston and Spencer (2018) find that US stock prices and house prices have increased above their fundamental value as a side effect of QE, but they find no evidence of exuberance in the stock and housing market price dynamics.[9] Other papers examine the effect of QE on equity markets, but do not relate the effect to exuberance (see Chen et al., 2016; Haitsma et al., 2016; Hattori et al., 2016; Claus et al., 2018; Al-Jassar and Moosa, 2019).

Second, some studies use a similar approach and investigate asset classes that are directly targeted by the purchase programmes (e.g. Van Lamoen et al. (2017)), whereas we study the effect on an asset class that is not directly targeted. The paper is therefore related to Borio and Zhu (2012), who introduce the risk taking channel of QE as the impact of monetary policy on the willingness of market participants to take risk, which influences economic decisions in the real economy. Bekaert et al. (2013) also relate monetary policy to the stock market and find a close relation between Fed interest rate cuts and perceived risk in US equity markets. In a similar fashion, Hattori et al. (2016) report a significant decrease in the perception of crash risk in US equities surrounding Fed QE announcements, resulting in higher valuations, and lower volatility.

Third, we contribute to the growing body of literature that uses the GSADF test to identify asset pricing bubbles in a wide range of financial assets.[10] So far, studies primarily focus on the response of asset prices to key policy announcements (cf. Krishnamurthy and Vissing-Jorgensen, 2011; Altavilla et al., 2015; Hattori et al., 2016) and do not examine whether investors exhibit exuberance surrounding the announcement of QE.

Last, we shed light on bubble dynamics by examining the likelihood that exuberant price behaviour persists in future periods, which has not been done in this context before.

The paper is structured as follows. Section 2 outlines the data and the two parts of the methodology; the bubble identification procedure and the explanatory analysis to the drivers of the exuberance. Section 3 provides an overview of the results of both parts of the analysis and Section 4 concludes.

2 Data and Methodology

2.1 Data

We focus on stock price dynamics in 10 core euro area countries: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Portugal, Spain and the Netherlands, over the period January 1996 − May 2018.

For each country, we extract the MSCI country index from Bloomberg.[11] Using MSCI indices has two advantages. *First*, MSCI country indices are broader and more stable than other country indices such as the AEX (i.e. they have a broader coverage without frequent changes in their composition).[12] *Second*, the MSCI indices are available over a longer period than the national indices (our Bloomberg data on prices and earnings from MSCI-indices start from January 1996).

[9] A deviation from the fundamental value and exuberance have a different meaning in this paper. A deviation from the fundamental value refers to the level of a variable, whereas exuberance refers to an explosive change in the variable (1^{st} difference).

[10] For housing prices see Afsar and Dogan, 2018; Engsted et al., 2016; Pavlidis et al., 2019; Fausch and Sigonius, 2018; Pavlidis et al., 2016; Huang and Shen, 2017; for REIT indices see Escobari and Jafarinejad (2016); alternative energy stock market see Bohl et al. (2015); for oil prices see Caspi et al., 2018; Pavlidis et al., 2013; Sharma and Escobari, 2018; Su et al., 2018 for exchange rates see Bettendorf and Chen, 2013; Jiang et al., 2015; Hu and Oxley, 2017; for the Bitcoin see Cheung et al., 2015; Corbet et al., 2018 and for precious metals (gold, silver, platinum and palladium) see Figuerola-Ferretti and McCrorie (2016).

[11] More information on these indices can be found on `https://www.msci.com/countries-heat-map`. Note that the indices reflect the market capitalization of the different stocks. Therefore, the composition of the indices differs per country (e.g. financials have a bigger share in Italy than in the Netherlands).

[12] See StarCapital Research (2016), *Predicting Stock Market Returns Using the Shiller CAPE.*

If we would merely test the stock price on exuberant behavior, the GSADF test could falsely identify a bubble when an increase in price is justified by improving fundamentals (i.e. make a type I error). We therefore use a widely accepted and used measure in finance as an indicator of over-/undervaluation: the Cyclically Adjusted Price Earnings (CAPE) ratio, also known as the Shiller P/E ratio (after Robert Shiller).[13,14] This P/E ratio is corrected for business cycles and inflation (for which an average period of 10 years is typically considered to be appropriate). The resulting measure is a more stable and reliable measure of equity valuations as the more volatile and cyclical components of earnings and inflation are filtered out (see e.g. Campbell and Shiller, 1988; Shiller, 2000; Taboga, 2011).

We use monthly data to calculate the CAPE. The dataset contains the price of the national MSCI index, combined with the earnings per share and inflation data (HICP). On the basis of these values, the CAPE ratio follows from dividing the real price by the average real earnings (over a rolling window of 10 years historical data). What follows from the calculations is the P/E ratio which is corrected for inflation and cyclical movements, where earnings capture the fundamentals of a stock price.

The resulting time series of CAPE ratios are depicted in Figure 3 along with their descriptive statistics in Table 1. There are substantial differences between euro area countries. First, Spain shows the highest value for the CAPE index at the end of our observation period, followed by Austria and Italy. This reflects the stalled recovery in asset prices in the years after the financial crisis. Especially Spain experienced a rapidly increasing equity market during the end of our sample period, whilst the country also experienced a deep recession - with negative real earnings - in the years after the financial crisis and during the sovereign debt crisis. Moreover, the figure shows that the divergence between the CAPE ratios has become wider post financial crisis. This greater divergence is a result of the impact of the financial crisis on the various economies and stock markets. For instance, where Spains stock market has recovered a large part of the loss suffered after the financial crisis, Portuguese stocks are still trading well below this level.

2.2 Explanatory variables of stock price bubbles

To the best of our knowledge, there is no literature that explicitly establishes whether QE, in combination with macroeconomic and financial variables, coincides with (statistical) exuberance in stock markets. Furthermore, there is no previous literature that includes an exhaustive list of relevant macroeconomic drivers of exuberance in equity prices. However, there is literature that explicitly links macroeconomic variables to movements in stock prices. To identify possible macroeconomic drivers that increase the probability of (statistical) exuberant behaviour we therefore use those that are proven to be significantly related to equity price movements.

The growth rate of industrial production is expected to be positively related to stock prices. Growing production can reflect more demand, and has the potential to drive up (expected) cash flows and thus equity prices (cf. Fama, 1981; Chen et al., 2016; Cheung and Ng, 1998; McMillan et al., 2001; Humpe and Macmillan, 2009). In a similar fashion, Fama (1981) finds a positive relation between GDP growth and stock prices. Asprem (1989) reports that the unemployment rate is an indicator of economic growth and consequently tells us something about the equity market. Boyd et al. (2005) show an ambiguous relation between the unemployment rate and stock prices; the effect changes sign depending on the state of the economy but proves to be significant. Moreover, Rapach et al. (2005) find that long term interest rates also reflect expectations about future growth as investors price expected short term rates over a longer horizon, and thereby

[13] *"Robert Shillers cyclically adjusted price-earnings ratio, or CAPE ratio, has served as one of the best forecasting models for long-term future stock returns"* (Siegel, 2016, p.41).

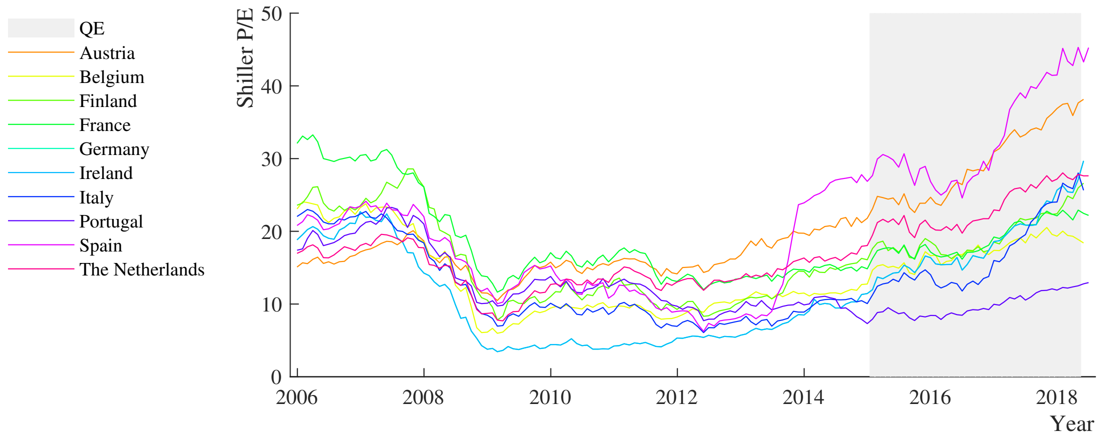
[14] See also the website `http://www.econ.yale.edu/~shiller/`.

Table 1: Descriptive statistics MSCI and Shiller P/E (DECEMBER 2005-MAY 2018)

MSCI Index	Obs.	Mean	Std. dev.	Min.	Max.
Austria	150	120.22	17.84	68.87	170.19
Belgium	150	77.96	24.89	32.32	109.70
Finland	150	108.67	29.73	61.04	195.91
France	150	120.52	22.20	72.32	161.39
Germany	150	116.64	24.42	61.52	163.30
Ireland	150	48.43	28.95	20.16	124.76
Italy	150	68.01	23.77	39.18	126.67
Portugal	150	61.99	23.56	35.00	123.86
Spain	150	117.58	23.11	66.24	180.15
Netherlands	150	97.28	24.84	48.97	148.32
Shiller P/E					
Austria	150	19.04	5.09	13.44	31.14
Belgium	150	14.67	6.04	4.73	27.67
Finland	150	16.41	5.71	7.80	28.58
France	150	18.78	5.77	11.64	33.26
Germany	150	19.69	4.41	11.48	30.81
Ireland	150	11.94	7.07	3.45	29.69
Italy	150	13.38	5.80	6.07	28.02
Portugal	150	12.36	4.14	7.31	23.28
Spain	150	20.74	9.94	6.24	45.29
Netherlands	150	16.85	4.84	7.69	28.04

Note: Table 1 shows the Shiller P/E ratio calculated as the real price divided by the average real earnings over a period of ten years for all the countries in the sample. December 2005 is the first moment the Shiller P/E is available due to the computation of the 10 year average earnings. Calculations are based on MSCI country indices for Austria, Belgium, Finland, France, Germany, Ireland, Italy, Portugal, Spain and The Netherlands. Inflation data is provided by Eurostat and extracted from Bloomberg. We use backward looking earnings data from Bloomberg on the country specific MSCI indices. Monthly inflation data is interpolated from quarterly data when unavailable. Source: Authors calculations, Bloomberg, Eurostat

Figure 1: Shiller P/E ratio calculated for MSCI indices in the sample



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have to make an assessment on future inflation. In addition to nominal rates, the slope of the yield curve is considered as a predictor of economic growth. In times of low economic growth an upward sloping yield curve signals adverse conditions in current periods, but improved conditions in the near future. The opposite applies for an inverted yield curve (Estrella and Hardouvelis, 1991; Ang et al., 2006). Multiple other studies find a positive relation between credit growth to non-financial institutions and booms followed by busts (e.g. Jordà et al., 2015).

Table 2 gives an overview of the macro variables included in our panel, along with the sign of the relation with equity prices and the expected sign of the relation with the formation of stock market bubbles. We use the 10-year government bond yield as a proxy for bond rates in general, as interest rates on government debt stand out in terms of predictive ability across countries (cf. Rapach et al., 2005). Furthermore, the 10 year maturity is often used in academic studies (see De Haan and Van den End, 2018). In addition, the shadow short rate (SSR) is used in order to capture the relation between finding stock market exuberance and short-term interest rates. Although the EONIA index can also be used to this extent (see e.g. Van Lamoen et al., 2017), it has been trading flat for quite some period of time as a result of the effective lower bound. The SSR tries to approximate what the short-term interest rate would have been, if there was no effective lower bound. SSRs are used as indicator of the stance of monetary policy in unconventional as well as conventional environments (see Krippner, 2012, 2013, 2015, 2016; Bullard et al., 2013; Wu and Xia, 2016).[15] As for longer term interest rates, the expected relation with stock prices is negative. However, the relation with bubble formation is not so clear. On the

[15] Krippner (2016) points to two issues when using SSRs. First, negative values of SSRs do not represent interest rates at which economic agents can transact. *Therefore, the levels and changes in SSRs when they are negative should not necessarily be expected to influence the economy in the same way as policy rate levels and changes in conventional policy periods.* Second, there is variation in the magnitude and profile of SSR estimates within unconventional periods, depending on the model. Sometimes the variation is substantial.

one hand, one would expect a negative relation (leaning against the wind to deflate a bubble), but on the other hand an increase in the short term interest rate could even lead to an increase in the bubble component of a stock price (in contrast to the fundamental component) (Galí, 2014 cf. the bubble model of Scherbina and Schlusche, 2014).

In addition to these macroeconomic variables, we add two indicators of financial markets, namely trading volume in a particular stock and volatility of the stock price. Literature reports a positive effect of both variables on stock prices (see Scheinkman and Xiong, 2003; Albertazzi et al., 2018). Hong and Stein (2007) argue that trading volume appears to be an indicator of sentiment: returns tend to be lower when a stock has a higher trading volume. There is also evidence these variables relate to asset price bubbles. Although very different in methodology than this paper, Narayan et al. (2013) find that trading volumes and share price volatility have statistically significant effects on asset price bubbles. We incorporate these variables as the logarithm to address skewness issues that arise when taking the unadjusted data. The volatility is measured as the 30-day rolling window standard deviation of the equity return. Note, we do not include the consumer price index (HICP, monthly change) as explanatory variable. Although it is expected to be negatively related to stock prices (e.g. Asprem, 1989; Cohn and Lessard, 1981; Campbell and Vuolteenaho, 2004), we already use real stock prices and real earnings, so we do no longer have to correct for the effect of inflation on bubble formation in addition to these corrections. Table 3 depicts some basic characteristics of the explanatory variables included in the panel data.

Table 2: Macro fundamentals and the expected relation to the stock market

	Relation to the stock market	Related literature	Relation to bubble formation	Related literature
Yield 10Y	-	Campbell and Shiller (1988)	-	
Shadow short rate	-	Thorbecke (1997), Bernanke and Kuttner (2005)	?	Roubini (2006); White (2006); White et al. (2009); Borio and Zhu (2012); Galí (2014); Galí and Gambetti (2015)
Monthly real GDP growth	+	Fama (1981); Chen et al. (1986)	+	
Monthly growth in industrial production	+	Fama (1981)	+	
Unemployment rate	?	Asprem (1989); Bohl et al. (2015)	?	
Monthly credit growth to the non-financial sector as % of GDP	?		+	Schularick and Taylor (2012); Jordà et al. (2013); Jordà et al. (2015); Pavlidis et al. (2019)
Trading volume	+	Hong and Stein (2007); Narayan et al. (2013)	+	Hong and Stein (2007); Narayan et al. (2013)
Volatility	+	Narayan et al. (2013)	+	Narayan et al. (2013)

Note: Table 2 shows the explanatory variables we take into account when explaining (statistically) exuberant behaviour in equity prices. +/- reflects the expected sign of the relation to stock market (bubbles). (?) means we did not find an expected ex-ante relation in the current literature, either because literature mentions a negative as well as a positive relation or there is no literature documenting this relation. If there was no literature available on the relation between a variable and the bubble formation, our best guess is a similar relation as the expected relation to the stock market, because the dependent binary variable is derived from the process of the underlying stock price. All growth variables are the percentage change over a one month period. For credit growth the monthly growth is interpolated from quarterly data using a linear interpolation method. Source: Authors calculations, BIS, Bloomberg

Table 3: DESCRIPTIVE STATISTICS PANEL DATA (NOVEMBER 2007-MAY 2018)

	Obs.	Mean	Std. dev.	Min.	Max.
10Y yield	1270	2.87	2.07	-0.13	15.67
Log volatility	1270	2.96	0.46	1.72	4.71
Log volume	1270	21.70	1.95	17.90	26.42
Change in unempl. rate	1260	0.01	0.19	-0.80	1.10
Change in indust. prod.	1260	0.04	3.19	-22.60	33.20
Real GDP growth	1260	1.02	3.53	-9.50	27.60
Growth in credit to non-financial sector	1260	0.30	2.54	-15.40	30.90
Shadow short rate	1270	-1.44	2.89	-7.68	4.41

Note: Table 3 gives the descriptive statistics for the explanatory variables in Model (1) - Model (8) over the sample period November 2007-May 2008. 10Y yield is the average yield over the 10 countries in the panel (Austria, The Netherlands, Belgium, Italy, France, Germany, Spain, Portugal, Finland and Ireland). N=1260. Log volatility is the logarithm of the trading volatility, Log volume is the logarithm of the daily trading volume for the respective country MSCI indices. The change in unemployment and industrial production reflects the monthly change in the variables on country level. Real GDP growth and the growth in credit to the non-financial sector are the growth rates in both indicators. The shadow short rate reflects the SSR for the euro area as calculated by Krippner, the data is obtained from the Reserve Bank of New Zealand. Credit growth to the non-financial sector is obtained from the BIS. For credit growth and GDP the monthly growth is interpolated from quarterly data using a linear interpolation method. Source: Authors calculations, BIS, Bloomberg, Reserve Bank of New Zealand.

2.3 Identifying asset bubbles: The GSADF procedure

If investors are fully rational and have access to all relevant information, the ratio between the prices and average earnings would be approximately at a constant level, i.e. the stock price should relate to the (expected) earnings and would only deviate due to a random unexplained component. However, when the real price increases substantially faster than the fundamentals (i.e. average real earnings), the CAPE ratio we use would increase and - if it does so in an explosive manner - the GSADF test would detect exuberant price behaviour.

The GSADF procedure is developed by Phillips et al. (2015) and examines to which extent the corrected price series exhibits explosive behaviour. The test is based on the Augmented Dickey-Fuller (ADF) unit root test, but distinguishes a unit root from explosive price behaviour (instead of a unit root versus stationarity of a time series based on conventional ADF tests). Moreover, the GSADF procedure applies the ADF test recursively by dividing the full observation period in smaller time windows. This is done to overcome the risk of underestimating bubbles in periodically collapsing time series (i.e. making a type II error)(Evans (1991)).

We make use of basic asset pricing principles, where the pricing formula for a stock is often used as a starting point to identify bubbles (Phillips et al., 2015). The price of a stock is given by:

$$P_t = \sum_{i=0}^{\infty} \frac{1}{1+r_f}^{i} E_t(D_{t+i} + U_{t+i}) + B_t \tag{1}$$

where P_t is the price of the asset, D_t is the payoff received from the asset (i.e. dividend), r_f is the risk-free interest rate, U_t represents the unobservable fundamentals, and B_t is the bubble component (Phillips et al., 2015, p. 1046). B_t satisfies the sub-martingale property:

$$E_t(B_{t+1}) = (1 + r_f)B_t \tag{2}$$

Equation 1 shows that when the bubble component is absent (i.e. $B_t = 0$), the degree of (non)stationarity of the stock price is dependent on the expected dividend series and unobservable fundamentals. As also argued by Phillips et al. (2015), expectations for unobservable fundamentals U_{t+i} are at most integrated of the first order $I(1)$ and dividends are stationary after differencing. Intuitively, the price of the stock would be infinite when the expectations for the unobserved fundamental or dividend would be an explosive process. On the contrary, given equation (2), stock prices will be explosive in the presence of bubbles. Therefore, when we find explosive behaviour in stock prices, this may be used to infer the existence of bubbles.

In order to detect the (explosive) bubble component in asset prices it therefore makes sense to use a statistical test for explosive behaviour (i.e. test for a unit root). As a starting point the Augmented Dickey-Fuller test regression is:

$$\Delta y_t = \hat{\alpha}_{r_1,r_2} + \hat{\beta}_{r_1,r_2} y_{t-1} + \sum_{i=1}^{k} \Psi^i_{r_1,r_2} \Delta y_{t-1} + \hat{\epsilon}_t \tag{3}$$

where Δy_t is the corrected asset price in first differences ($y_t = CAPE_t$), 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.[16] The time series contains a unit root under the null hypothesis $H_0 : \pi_{r_1,r_2} = 0$, while an explosive process (a characteristic of an asset price bubble) is assumed under the alternative hypothesis, $H_1 : \pi_(r_1, r_2) > 0$. The ADF test statistic is:

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

The GSADF procedure boils down to an ADF test for various time-windows with different begin- and endpoints in the time series. In the first step the procedure identifies sub-periods of exuberant behaviour within the entire period. This is done by the Backward Sup ADF (BSADF) test, which fixes the end point of the data at r_2 and subsequently uses the ADF test to identify an explosive process on a backward expanding sample sequence. The GSADF procedure then uses multiple sub periods by varying both the starting and ending point r_1 and r_2 (moving window technique), since using a fixed termination window (i.e. ending point r_2) would not allow us to fully capture the buildup of exuberant price behaviour (and potential collapse afterwards). The GSADF test is the supreme value of the BSADF statistics. Compared to alternative existing testing procedures, the GSADF test is better able to detect explosive behaviour if multiple bubbles exist due to the recursive estimation procedure with flexible starting and ending points (Phillips et al. (2015)).[17] The test statistics for both the BSADF and GSADF depend on the starting point of the sample r_1, the ending point of the sample r_2, and the minimum time window needed to perform the test (indicated as a fraction represented by r_0):

$$BSADF_{r2}(r_0) = \begin{matrix} sup \\ r_1 \in [0, r_2 - r_0] \end{matrix} \left\{ ADF^{r2}_{r1} \right\} \tag{5}$$

$$GSADF_{r2}(r_0) = \begin{matrix} sup \\ r_2 \in [r_0, 1] \end{matrix} \left\{ BSADF_{r2}(r_0) \right\} \tag{6}$$

[16] $\hat{\epsilon}_t$ is the error term that follows a white noise process, with $\hat{\epsilon}_t$ $N(0, \sigma^2)$

[17] Estimating the test regressions over the full historical observation period may lead to the result that bubbles are not detected if multiple bubbles are present and upward and downturn movements cancel each other out.

The GSADF statistic in equation 6 is only used to indicate exuberance over the whole time period, but provides no information with regard to the exact timing of exuberance in sub-periods. To identify whether prices exhibit explosive behaviour at each point in time, Phillips et al. (2015) recommend a date-stamping strategy based on the BSADF statistic in equation (5). 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.[18] 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. This is captured by the following two equations:

$$\hat{r_e} = \underset{r_2 \in [r_0, 1]}{inf} \left\{ r2 : BSADF_{r2}(r_0) > scv_{r_2}^{\beta_T} \right\} \tag{7}$$

$$\hat{r_f} = \underset{r_2 \in [\hat{r_e}, 1]}{inf} \left\{ r2 : BSADF_{r2}(r_0) < scv_{r_2}^{\beta_T} \right\} \tag{8}$$

where $scv_{r_2}^{\beta_T}$ is the $100(1-\beta_T)\%$ critical value of the sup ADF statistic based on $[T_{r_2}]$ observations. Equation (7) indicates the starting point of exuberant prices that deviate substantially from fundamentals while equation (8) denotes the ending point that characterizes a situation where prices and fundamentals become more aligned.

The implementation of the recursive testing procedure also requires the limit distributions of the BSADF and GSADF test statistics in order to calculate critical values (see Phillips et al., 2015, 2013). These distributions are non-standard and depend on the minimum window size. Therefore, critical values have been obtained through Monte Carlo simulations. We calculate the finite sample of critical values by generating 2,000 random walk processes with $N(0, 1)$ errors. A final remark on this test is that it signals both upward and downward exuberant behaviour, i.e. an overreaction in terms of selling the asset could also fit the bubble criteria. Therefore, we should always take into account the direction of the move in the underlying asset price when interpreting the result.[19]

2.4 Drivers of stock price bubbles

In addition to macroeconomic drivers described in Section 2.2 and financial variables, our study also captures time dynamics in stock price exuberance by examining its persistence over time. When a bubble is detected in a period there may be a higher likelihood that it will persist in the next period as well, conditional on not completely deflating in the previous period. This information might have explanatory power for the current likelihood that stocks are exhibiting exuberant behaviour. In order to account for such effects we use a dynamic probit model with random effects. The dynamic model allows us to investigate the persistence of explosive behaviour over time. In our study we use the conditional maximum likelihood estimator of Wooldridge (2005).[20] The GSADF test in combination with a dynamic probit model is also used by Huang and Shen (2017). However, they analyze housing price dynamics in Hong Kong and drivers that influence the likelihood of exuberance in this market.

[18] Furthermore, a backward expanding process is better able to detect bubbles at the end periods of the historical data series.

[19] For example, a financial crisis may result in stock prices decreasing rapidly which may be captured by the GSADF test as explosive price behaviour (but in a downward spiraling market).

[20] See Arulampalam and Stewart (2009) for a comparison of alternative dynamic probit estimators to deal with the initial conditions problem.

A panel data model is constructed by pooling the data on drivers per country and by creating a binary dependent variable that indicates whether exuberance is observed at each point in time with a certain confidence level (see equations (7) and (8)). In our main specifications a confidence level of 95% is used.

$$y_{i,t} = \begin{cases} 0, if BSADF_{r_2,it}(r_o) > scv_{r_2}^{\beta_\tau} \\ 0, if BSADF_{r_2,it}(r_o) < scv_{r_2}^{\beta_\tau} \end{cases} \tag{9}$$

The dynamic probit model is based on a standard probit specification with different assumptions on the unobserved heterogeneity. In general terms, the standard probit model can also be formulated based on a model with the latent variable $y_{it} = 1[y_i t^* > 0]$:

$$\Delta y_{it}^* = \rho y_{it-1} + x_{it}^{'} \beta + \theta_t \alpha_i + u_{it} \tag{10}$$

where y_{it} denotes the lagged dependent variable in the latent model, $x_{it}^{'}$ a vector of exogenous variables, α_i represents the random effects and u_{it} is the error term. The parameter θ_t is used to identify σ_α^2 and the equation for the first period:

$$\Delta y_{i0}^* = z^{'} \omega + \theta_0 \alpha_i + u_{i0} \tag{11}$$

where $z^{'}$ is specified to be $x\prime$ using the information in periods 1 to T to solve the initial condition problem (similar to the Mundlak specification, see Arulampalam and Stewart, 2009). Therefore $z^{'}$ is a vector of exogenous variables $x^{'}$. Wooldridge (2005) approximates the density of the random effect α_i conditional on the initial observation y_0. The dynamic probit model with random effects can be formulated as:

$$Pr(y_{i,t} = 1 | \alpha_i, y_{i,0}) = \Phi[x_{i,t}^{'} \beta + \rho y_{it-1} + \delta_i y_{i,0} + z_i^{'} \delta + c], t = 1, ..., T \tag{12}$$

where α_i is substituted by $\alpha_i = \delta_0 + \delta_1 y_{i0} + z_i^{'} \delta + c_i$. The contribution of each country i to the likelihood function is specified as:

$$L_i = \int \Big\{ \prod_{t=1}^{T} \Phi[(x_{i,t}^{'} \beta + \rho y_{it-1} + \delta_i y_{i,0} + z_i^{'} \delta + c)(2y_{it} - 1)] \Big\} g^*(c) dc \tag{13}$$

where $g^*(c)$ is the normal probability density function of c_i.

In alternative specifications (included in the Annex) we apply both a linear probability model and conditional logit model accounting for fixed effects. By using fixed effects we first assume the unobserved country specific effects (heterogeneity) in the panel are constant over time and correlated to the independent variables and the error term. A linear probability model also has its flaws as the estimates of are not restricted to a value within the plausible probability range [0,1]. The conditional logit model does not have this flaw and makes the implicit assumption that the variables in the model follow a logistic cumulative distribution (as opposed to the probit model that is based on the standard normal cumulative distribution function).

As a further robustness check a random effects probit model without lagged dependent variable is used, to examine the robustness of our results (this model is for example used in Pavlidis et al., 2019). It makes slightly different assumptions regarding the unobserved country effects. The country effects are uncorrelated to the independent variables and the parameters are modelled as random variables drawn from a normal distribution. By assessing other model specifications we check whether our results might be driven by one of the underlying assumptions of the dynamic probit model, such as the presence of autocorrelation in the bubble component.

Table 4: Defined QE Dummies

QE dummy	Period
QE1	January-February 2015
QE2	March-April 2015
QE3	May-June 2015
QE4	July-August 2015
QE5	September-October 2015
QE6	November-December 2015
QE7	January 2016-May 2018

Note: Table 4 gives the periods in which the QE time response function equals 1. The variables are included in model specification (2), specification (4), specification (6) and specification (8) in Table 6. We also include a QE0 dummy for the period between August 2014 and December 2014 to control for an anticipation effect. The results are included in Table 13 (Appendix).

The estimated model specifications include the macroeconomic and financial drivers, and specifications with and without the set of QE dummy variables. The QE dummies are added to the model as a time response function in a similar way as Wolfers (2006), a modelling technique that is also used by Bos et al. (2013) and Van Lamoen et al. (2017). The PSPP announcement was in January 2015. The time response dummy variables are split into 7 dummy variables, where dummy variable 1-6 each capture a two-monthly response. By constructing the dummies in the same way as Wolfers (2006) we limit the model impact on the structure of the time-effects. This results in the variables QE1-QE7. QE1 captures the announcement of QE in January 2015. QE2 captures start of the Expanded Asset Purchase Programme (EAPP, March 2015). Table 4 shows the periods in which the different QE dummies are 1 and 0 otherwise. Using only one dummy (for example at announcement) does not allow for a dynamic response in the course of time. Yet, the possible effect of QE may differ through time. For example, the effect after announcement may differ from the effect after implementation.

As the GSADF method also detects downward explosive behaviour, we use a crisis dummy during 2008 and 2009 to correct the other estimators in the model for the sharp decline in stock prices over this period.

3 Results

3.1 Explosive behaviour in stock prices

Based on the GSADF statistic we find multiple significant explosive periods in five out of ten countries in our panel data set (Table 5). The most statistically significant results are found for Belgium, Ireland and Italy. The stock markets in the Netherlands and Spain also show multiple periods of exuberance, but on a lower significance level (5% and 10% respectively).

The results in Table 5 only show whether significant exuberance is observed for each country during the historical observation period. However, Table 5 does not show in which specific month(s) exuberance is observed. To identify the sub periods with exuberant behavior, we can use the BSADF statistics in equations (7) and (8). Based on the BSADF results we observe sub periods of explosive price behaviour in all ten countries throughout the sample, with the first period of exuberance starting during the stock market crash in 2008 (Figure 2). These results signal an explosive decrease in prices during the financial crisis, i.e. a deflating asset bubble or a

Table 5: Results multiple bubbles (GSADF)

Country	GSADF Statistic (Sup BSADF values)
Austria	1.2763
Belgium	4.0012***
Finland	1.4877
France	1.5420
Germany	1.2379
Ireland	3.2977***
Italy	3.2478***
Portugal	0.8936
Spain	2.2492*
Netherlands	2.4433**

Note: Table 5 gives the results for the GSADF test procedure as described in equation (6). The GSADF value indicates whether there are periods of exuberance in the country specific Shiller P/E ratio over the period October 2008-May 2018. Significant results show the presence of exuberance in the time sample at *10%, **5% and ***1% significance levels. GSADF critical values for confidence levels of 0.90, 0.95 and 0.99, are 1.9880, 2.3143 and 2.9372, respectively.

possible overreaction by market participants. Another result that directly draws attention is the long period of explosive price behaviour in Ireland's stock market, which started in July 2013 (on a 90% confidence level) and remained significantly higher than the critical test values until the end of May 2018. This outcome possibly results from the (financial and debt) crisis that hit Ireland more than other countries. To illustrate, the earnings per share dropped to -0.64 for the MSCI Ireland compared to 1.57 for the MSCI Europe. Moreover, in the period after the crisis earnings show a slow recovery compared to the value of the stock. This results in a low average price to earnings in the post-crisis period (1.29 versus 5.8 for the MSCI Europe). We find a similar result for Belgium where earnings per share dipped into negative territory during the financial crisis (-3.86). Intuitively, stock markets that show a bigger decline in earnings during economic stress - i.e. have higher earnings volatility - are more risky, and therefore should have lower valuations. For these stock markets a period of (rapidly) rising stock prices is more easily qualified as exuberant, as the Shiller P/E ratio of the stock more easily increases when stock prices go up (denominator effect).[21] On the contrary, it stands out that Germany is the only country that does not experience a new period of exuberance. This can largely be explained by the robust recovery in earnings and the relatively low earnings volatility for the companies in the MSCI Germany, which justifies increasing share prices (earnings per share of 7.3 versus 5.8 for the MSCI Europe).

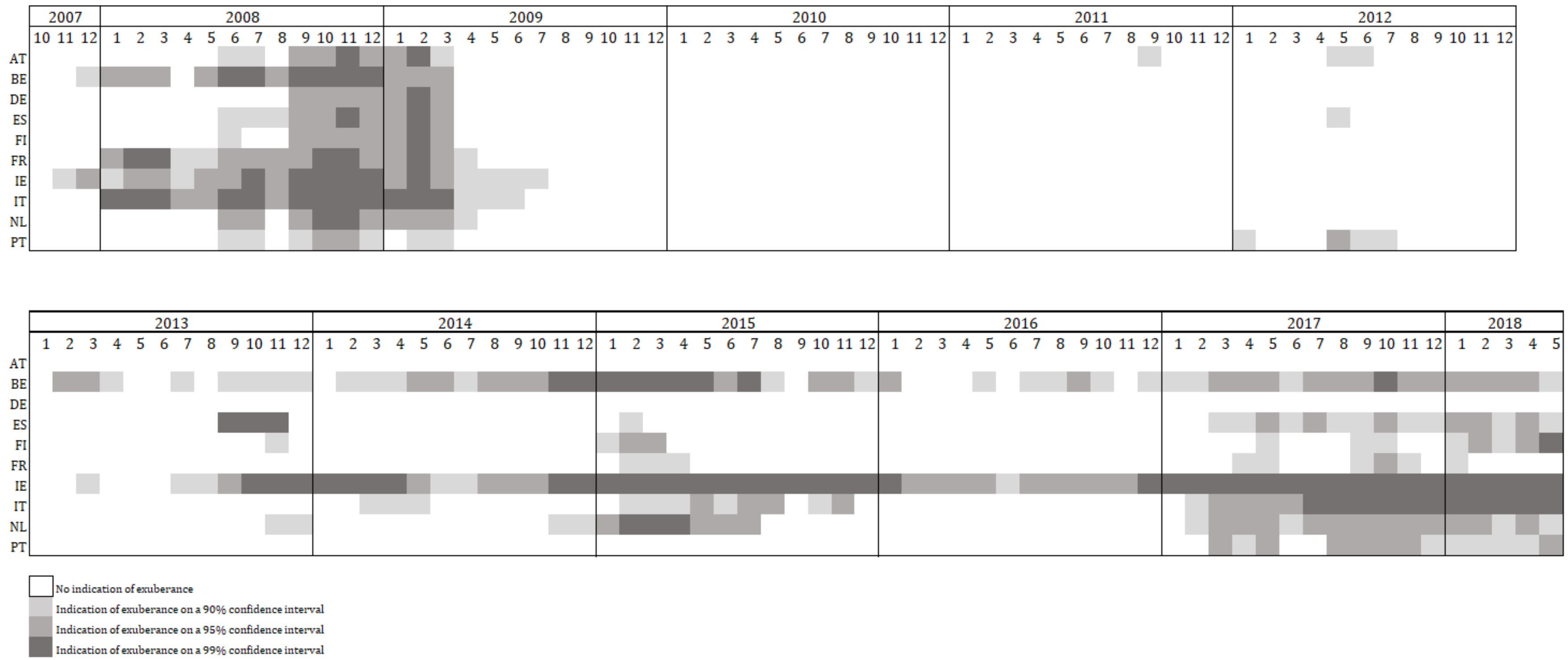
In addition to 2008, there are two other periods where we find significant exuberance in stock prices in multiple countries. The results show that stock prices in Belgium, Spain, Finland, Ireland, Italy and the Netherlands started to exhibit exuberance in early 2015. In contrast to 2008, this results from rapidly increasing stock prices. A third period of exuberance can be observed in 2017. This started in Italy and the Netherlands, but over time also other European stock indices exhibited explosive price behaviour, with the exception of Austria and Germany. In

[21] One could make a similar argument for stock markets in all GIIPS countries. However, the recovery in equity markets in Portugal has been much more robust in terms of the Shiller P/E ratio. i.e. earnings increased substantially with the price of equities. Spain primarily shows exuberance during the QE period and not prior to 2014, making the null hypothesis of multiple bubbles (GSADF) easier to reject.

May 2018 this explosive behaviour was significant at a 99% level for Belgium, Finland, Ireland and Italy. The observed exuberance is quite persistent as it endures through the end of our observation period for all countries except Germany, Austria and France.

The results seem to indicate that the announcement and the start of QE played a role, as there is explosive behaviour in the prices around the start of 2015. However, to make robust statements about what is driving exuberance we should correct for the factors discussed in Section 2.

Figure 2: Shiller P/E ratio calculated for MSCI indices in the sample



Note: Figure 2 shows the Shiller P/E ratio calculated as the real price divided by the average real earnings over a period of ten years for all the countries in the sample. Calculations are based on MSCI country indices for Austria, Belgium, Finland, France, Germany, Ireland, Italy, Portugal, Spain and The Netherlands. Inflation data is provided by Eurostat and extracted from Bloomberg. We use backward looking earnings data from Bloomberg on the country specific MSCI indices. Monthly inflation data is interpolated from quarterly data when unavailable. Source: Authors calculations, Bloomberg, Eurostat.

3.2 Drivers of explosive behaviour in stock prices

Table 6 shows the main results of our panel data analysis. This analysis shows that QE is indeed positively related to stock market bubbles. Moreover, also after controlling for macro-economic fundamentals, periods of QE seem to be the main driver of the exuberance in our panel. We also find that months with exuberance are likely to be followed by another month of exuberance in our sample period, i.e. there is persistence in exuberance. This finding is in line with a stream of prior bubble literature that finds persistence in asset pricing returns (see Campbell and Shiller, 1987; Chou, 1988; Froot and Obstfeld, 1991; Koustas and Serletis, 2005). An often mentioned issue with empirical research on the impact of monetary policy on stock prices is the endogeneity between policy measures and adverse stock market scenarios (see Rigobon and Sack, 2003). Although stock markets may be part of policy makers reaction function, we believe this is less of a concern for the setup of this paper. Policy makers are unlikely to have introduced and increased QE measures due to rapidly increasing equity prices in the same period. Moreover, the reaction found in Rigobon and Sack (2003) to monetary policy announcements would imply a stronger relation between QE and exuberance (i.e. an underestimation of the effect).

3.2.1 Main specification

Models (2) and (4) in table 6 show the results of the two main models, i.e. the models where we add the effect of QE to the model. Model (2) shows that QE significantly contributes to explosive behaviour in stock prices, especially around the announcement (January 2015, QE1) and the start of the EAPP (March 2015, QE2). However, the significant effect for the QE2 dummy disappears when we add a crisis dummy to the model (model (4)). This is somewhat surprising since the crisis dummies capture the downturn of the financial crisis in 2008 and 2009. The dummy for the third period of QE (QE3) is also significantly positively related to exuberant stock price behaviour. We attribute the rapid increase in stock prices during this period to the dovish comments made by the ECB which had a notable effect on equity prices.[22] In addition to QE1, QE2 and QE3 we also find that QE7 significantly increased the chance of observing a stock market bubble. This could indicate that the longer QE is implemented in financial markets, the higher the probability of disturbances, as QE7 captures the period from January 2016 onwards. However, the QE7 dummy is probably the least accurate of the QE dummies, as it captures the longest time frame.

All QE dummies are also jointly significant, signaling that all QE periods combined had a significant impact on exuberant behaviour. After correcting for the change in the other factors in the model we still find that QE is one of the main drivers of periods of exuberance. Our results suggest that QE had an effect on top of what could be explained by the macro drivers in the panel. Adding time dummies to the model does not lead to different results (models 5-8)). A variable of special interest is the 10-year yield. The interest rate on government debt was directly targeted by QE and we therefore examine its relation to QE and exuberance more closely. Although we do not find a significant relation between the 10-year bond yield and exuberance, a simple Wald-test for joint significance shows there is a significant relation between the QE-dummies and the 10-year yield on the likelihood of a bubble.[23] This should not come as a surprise as QE drove down risk premia on government debt significantly (cf. Altavilla et al., 2015). Another remark we should make is that the GSADF test is mainly designed to capture a rapid increase in prices,

[22] The ECB announced it would step up bond-buying in the months prior to July to make sure the monthly average ECB target was met notwithstanding lower liquidity during the summer. Also, Benoit Cæuré made a series of dovish comments during the speech, sending equities higher (Cœuré, 2015).

[23] This joint significance test on the set of QE dummies and the 10-year yield may represent the combined impact of QE.

rather than that it tells us something about the absolute level. Once these QE announcements are priced in by the market, the GSADF is no longer able to detect a bubble. This might be an explanation for the fact that only certain QE dummies have a significant relation to exuberance, i.e. the announcement and start lead to exuberant stock prices, which thereafter remain on a higher level.

When we examine the other models in Table 6 we can make the following observations. Model (1) shows us that when QE is taken out of the model the main drivers of exuberant price behaviour (both downwards and upwards) are the existence of bubbles in the previous period, real GDP growth and the SSR (all positively related). Ex ante it was not clear whether GDP growth would contribute positively or negatively to bubbles in financial markets, as it contributes to the price as well as to fundamentals. We now find an increasing GDP relates to a higher probability of exuberant behaviour. Interestingly, the positive and significant effect of real GDP disappears when we introduce QE into the model. The SSR was expected to be negatively related to exuberance, as it captures the short term interest rate. Model (1) and model (3) however show the coefficient is conditional on taking into account a crisis period or adding QE dummies (model (2, 4, 6)). One possible explanation could be that the SSR contributed more to the bubble component of a stock price than to the fundamental part of the stock price, meaning that a higher interest rate increases a bubble rather than decreasing it (Galí, 2014). Also, periods of high GDP growth could coincide with policy rate hikes in our sample period, making the relation between the SSR and the bubble component opposite from the expected (negative) sign. Nonetheless, model (3) shows that as soon as we use crisis dummies, this effect disappears and the sign turns negative. By using crisis dummies the effect of the explanatory variables on downward exuberance is filtered out.

Table 6: DRIVERS OF EXUBERANCE IN A DYNAMIC PROBIT ANALYSIS

	1	2	3	4	5	6	7	8
	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE
Lagged Bubble	2.3478***	2.3324***	2.154***	2.2066***	2.405***	2.2610***	2.207***	2.1565***
	(0.1380)	(0.1454)	(0.1237)	(0.1390)	(0.1237)	(0.1390)	(0.151)	(0.175)
Yield10Y	-0.1583	-0.0847	-0.0686	-0.0244	-0.1633	-0.0897	-0.0749	-0.0299
	(0.1124)	(0.1088)	(0.1119)	(0.1094)	(0.1120)	(0.1092)	(0.1111)	(0.1101)
Volatility	0.2447	-0.2600	0.0037	0.0298	0.2557	0.2730	0.0172	0.0429
	(0.1633)	(0.1662)	(0.1410)	(0.1733)	(0.1632)	(0.1699)	(0.1407)	(0.1767)
Volume	-0.0587	0.0313	-0.0492	0.0067	-0.0578	0.0281	-0.0500	0.0016
	(0.1632)	(0.1847)	(0.1463)	(0.1643)	(0.1705)	(0.1886)	(0.1547)	(0.1700)
Unempl.	0.1633	0.2137	0.1301	0.1798	0.1689	0.2247	0.1329	0.1881
	(0.3181)	(0.2871)	(0.3270)	(0.2811)	(0.3159)	(0.2782)	(0.3245)	(0.2669)
Ind. Prod.	0.0138	0.0086	0.0182	0.0141	0.0135	0.0071	0.0182	0.0133
	(0.0220)	(0.0216)	(0.0200)	(0.0203)	(0.0219)	(0.0209)	(0.0200)	(0.0205)
GDP	0.0728***	0.0382**	0.0660***	0.0447	0.07299***	0.0388**	0.0662***	0.0455*
	(0.0210)	(0.0189)	(0.0253)	(0.0286)	(0.0230)	(0.0191)	(0.0253)	(0.0274)
CNF	0.0067	-0.0023	-0.0119	-0.0177	0.0048	-0.0044	-0.0134	-0.0194
	(0.0322)	(0.0269)	(0.0300)	(0.0284)	(0.0372)	(0.0320)	(0.0327)	(0.0329)
SSR	0.0898*	0.1978***	-0.0768	0.0189	0.0927*	0.2000***	-0.0744	0.0195
	(0.0534)	(0.0462)	(0.0478)	(0.0397)	(0.0526)	(0.0468)	(0.0486)	(0.0410)
QE1		1.6112***		1.3338**		1.6320***		1.3398**
		(0.5430)		(0.5290)		(0.5478)		(0.5384)
QE2		0.9242**		0.6123		0.9220**		0.6000*
		(0.3926)		(0.3803)		(0.3735)		(0.3631)
QE3		0.8744**		0.8023**		0.8858**		0.8091**
		(0.3491)		(0.3576)		(0.3836)		(0.3933)
QE4		0.4680		0.5624		0.4776		0.5654
		(0.6445)		(0.6400)		(0.5980)		(0.5970)
QE5		0.2800		0.2473		0.3171		0.2778
		(0.4037)		(0.4035)		(0.3036)		(0.3016)
QE6		0.4672		0.2395		0.4888		0.2592
		(0.5779)		(0.5769)		(0.6191)		(0.6083)
QE7		1.3012***		0.8300**		1.2951***		0.8182**
		(0.3897)		(0.4008)		(0.4060)		(0.4140)
Fixed effects	No	No	No	No	No	No	No	No
Time effects	No	No	No	No	Yes	Yes	Yes	Yes
Crisis dummy	No	No	Yes	Yes	No	No	Yes	Yes
N	1260	1260	1260	1260	1260	1260	1260	1260

Note: Exuberance is based on a 5% significance level. Column 5-8 contain time effects to account for seasonality, column 3, 4, 7 and 8 contain crisis dummies. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. For time effects a monthly dummy is used, while the crisis dummy is 1 during 2008 and 2009, 0 otherwise. Volatility and volume are in logs, unemployment rate, industrial production and real GDP in monthly growth rates. CNF refers to Credit to the Non-Financial sector as % of GDP and is also taken as a monthly change. Period November 2007-May 2018.

3.3 Robustnesss checks

In order to examine the sensitivity of the results we perform several robustness checks. We check whether the results are sensitive to the model specification, the chosen time response function for QE, and the significance level of the GSADF statistic.

First, our findings do not change when we use a linear probability model, conditional logit or (static) random effects probit model instead of the dynamic probit model. Only for the linear probability model with crisis dummy, QE1 and QE2 are not significantly related to exuberance. However, with a binary dependent variable the linear probability model is flawed as predicted values are not restricted between 0 and 1 (Cox, 1970). Rather, either a logit or a probit analysis should be used, depending on the assumption that is made regarding the distribution of the underlying stochastic process of the independent variables (logistic versus standard normal, respectively). The (static) logit and probit analyses confirm the results of the dynamic probit analyses.

Second, we test the model specification for a variety of different independent variables and combinations of these variables.[24] One can argue that instead of using both industrial production and real GDP growth, only one of both is needed in the model, as they are interrelated. Using one of both does not lead to noticeable different results, the same holds for using the unemployment rate as an indicator for economic growth or not. Also variations where industrial production and GDP growth are interchanged with the unemployment rate, do not lead to different conclusions: in all cases QE and the lagged bubble indicator stand out with a significant increasing effect on the likelihood of explosive behaviour in stock prices. Our results are also robust for the choice of shadow short rate (SSR). When we use EONIA instead of the SSR this does not change any of the outcomes.

Third, we model a possible anticipation effect of investors on the start of QE, following the speech of Draghi at Jackson Hole in 2014. To do so, we added QE0 to the model. This dummy is 1 during August 2014 (the Jackson Hole Speech) till December 2014. The results can be found in Table 13 (Annex). Indeed, the results indicate a significant anticipation effect resulting in exuberance in European stock markets at the end of 2014. Moreover, introducing the QE0 dummy also causes the QE4 and QE5 dummies to be (weakly) significant. However, this result does not change our main conclusions, as it further supports the second hypothesis (periods of QE coincide with exuberance).

Finally, the results from the main specification do not change when the GSADF significance-level is changed to 10%. On the contrary, the QE dummies are no longer significant when a threshold of 1% is used in the analysis. A possible explanation is that we have only very limited observations of exuberant price behaviour that is significant at 1%. Only Ireland, Italy and Finland show a bubble over a very limited amount of time periods (see Figure 2). Moreover, when we test for joint significance of the QE dummies on the 1% specification the combined QE dummies have a significant effect on the probability of a bubble.

4 Conclusion and Discussion

In January 2015, the ECB announced the start of a QE programme by directly buying financial market assets. These measures were considered a necessity to counter weak inflation dynamics in the euro area and maintain price stability. QE made the Eurosystem a significant buyer of assets on financial markets, raising the question of whether the voluminous purchase programmes triggered irrational behaviour among market participants. We specifically look at the effect of

[24]We also check the correlation matrix on multicollinearity (Variance Inflation Index (VIF) below 10).

QE on stock markets as the search for yield makes risky assets (such as equities) more vulnerable for overvaluation. In an environment with QE, risky assets pose an attractive investment against an alternative of low, or even negative yielding safe assets. This mechanism drives investors into more risky assets, thereby artificially suppressing risk premia. Although one of the intended effects of QE, artificially lowering risk premia introduces the risk of inflating asset pricing bubbles. The search for yield caused by QE could steer prices of risky assets to a level that lies above their fundamental value.

Based on a GSADF-test we examine whether stocks show exuberance in 10 key euro area countries. Subsequently, we test whether the periods of stock market exuberance coincide with QE. We control the results for other (macro) fundamentals that also increase the probability of exuberant behaviour in stock markets, such as the country's GDP growth, unemployment, industrial production, short and long term interest rates, trading volume and a proxy for the volatility risk premium (trading volatility). For the analysis we use a dynamic probit model to gauge the effect of QE in combination with control variables. This also enables us to model the persistence of exuberance over time.

The analysis has several key findings. *First*, the GSADF test indicates exuberance in five out of ten countries in the dataset. The (statistically) most significant stock market bubbles can be found in Italy, Ireland and Belgium. The data indicates that those results are driven by high earnings volatility for the companies in those countries, which results in more risk and therefore more deviation in the Shiller P/E. The stock markets in The Netherlands and Spain also show multiple periods of exuberance, but on a lower significance level (5% and 10%, respectively).

Second, the results suggest that the announcement and the start of QE led to an exuberant increase in the stock prices of most of the countries in our panel, even after controlling for improving (macro) fundamentals. In particular, around the announcement and start of QE (January, March 2015) European stock indices exhibited explosive price behaviour that could not be explained by any of the countries (macro) fundamentals. However, the effect was only short lived as after the initial explosive increase in valuations, prices leveled off towards the end of 2015 and during 2016, and we do not detect exuberance any longer. This might be explained by the nature of the GSADF-test. The test is designed to detect the build-up of a bubble, i.e. the explosive increase (decrease) in the stocks valuations. Once the changes in the stock price level of, the GSADF-test is no longer able to detect the presence of exuberance.

Third, towards 2017 and early 2018, the stock indices of almost all countries in the panel exhibit exuberant price behaviour again. This can indicate that investors did not fully price in the new equilibrium for risky assets around the start of QE. Furthermore, the significance of the QE dummy capturing the final period (QE7) signals that the probability of exuberance increases the longer the programme lasts.

Finally, we show that observing exuberance in the current period positively affects the likelihood of exuberance in future periods. This result is in line with prior literature studying the persistence of returns in the stock market and is in contradiction with the (semi) strong form of the efficient market hypothesis (see Chou, 1988 and Campbell, 1990).

Our findings have two main implications for future monetary policy. *First*, we argue QE should be complemented by adjusting macro prudential requirements to suit the buildup of risk in the financial system (similar to the argumentation of Biljanovska et al., 2019 and Houben et al., 2014). Our results indicate that the probability of exuberance increases the longer QE lasts. The increased risk of asset bubbles is an undesired side-effect of QE, which should be taken into account in the design of policy measures by the ECB. Especially against the backdrop of the announcement by the ECB to restart net asset purchases in November 2019 policymakers should be vigilant, and closely monitor equity market valuations in the euro area on the misalignment with fundamentals.

Second, the announcement of bond purchases by the ECB in January 2015 was accompanied by exuberant upward price behaviour in stock markets. Reversing the purchases could therefore cause deflation of the stock market bubble, i.e. downward exuberance. Consequently, this asks for a careful strategy regarding the end of net asset purchases, and phasing out the reinvestment of maturing bonds. The Fed showed that clear communication and a runoff strategy that is dependent on the economic outlook helps to avoid shocks to market prices. The ECB may consider a similar strategy by leaving the size of the total balance sheet reduction open and make it dependent on developments in the economy, economic outlook and financial markets.

Further research is recommended on several aspects. *First* of all, by using the Cyclically Adjusted Price Earnings (CAPE) ratio as a proxy for stock fundamentals, we use a backward looking indicator. Although it is often used as a proxy in academic studies and by market participants to measure over- or undervaluation of stocks, it would be interesting to see what happens if a more forward looking indicator is used (such as a measure of expected earnings instead of realized earnings), as normally a stock price is the result of discounting future cash flows. Another disadvantage of the CAPE is that the length of the averaging period determines the outcome of the ratio, which could lead to sensitive results to this modelling choice (see Annex B for Italy).[25]

Second, although the GSADF method works well in determining explosive price behaviour during the phase in which it builds up, it is less suitable to signal the continued existence of a bubble when it is no longer increasing. Methods to determine whether a higher price level is a higher equilibrium value (for example resulting from long periods with low interest rates that are expected to last in the future), or is truly a deviation from its (expected) fundamental value (also in the future), would be insightful to substantiate whether bubbles are expected to last. This is also why we recommend to use our indicator in combination with other metrics, such as the absolute level of P/E levels or indebtedness of certain sectors or countries, to estimate the value at risk when a bubble collapses.

Third, often exuberant price behaviour or bubbles are explained by irrational behaviour of investors. In this study we mainly looked at modelling financial and macro-economic factors to explain price developments of stock indices. An interesting addition consists of a model that also takes into account behavioural factors in asset pricing.

[25] The period is not as important for other countries in the sample that experienced a shallower drop in average earnings during the financial crisis.

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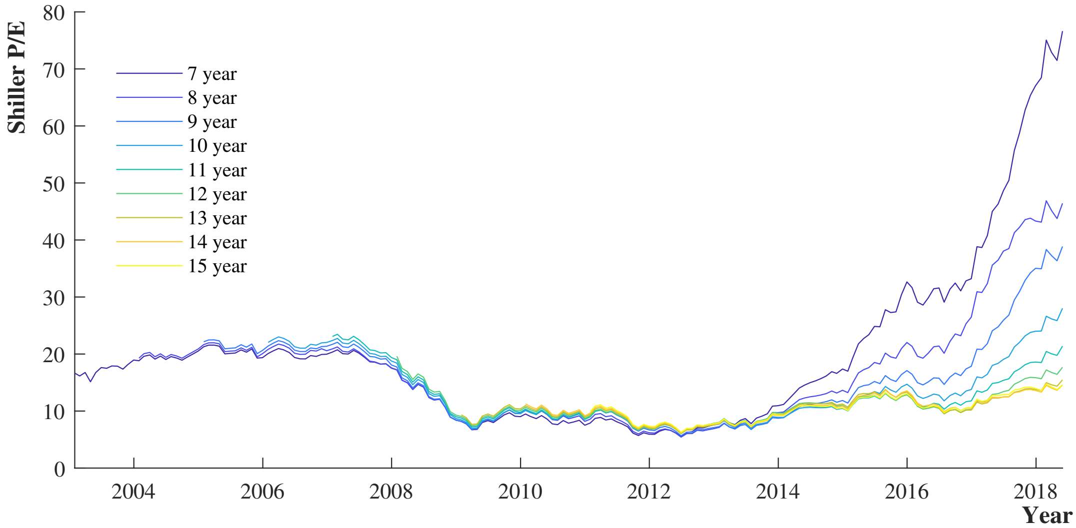
A Sensitivity of the Shiller P/E

Figure 3: Shiller P/E for Italy



Note: Figure 3 shows the Shiller P/E ratio calculated as the real price divided by the average real earnings over a period of ten years for Italy. Calculations are based on MSCI Italy for various periods of average earnings (7-15 year averages). Inflation data is provided by Eurostat and extracted from Bloomberg. We use backward looking earnings data from Bloomberg on the country specific MSCI indices. Monthly inflation data is interpolated from quarterly data when unavailable.

B Alternative specifications

The following tables show alternative specifications to our main model. Table 7 includes the results of a linear probability model, a conditional logit model and a random effects probit model for exuberance on a 5% significance level, without a crisis dummy. Table 8 includes the same models but adds a crisis dummy. Table 9 and Table 10 contain the results of our main specifications, but the confidence level of determining exuberance is changed to 10% and 1% respectively. Table 11 contains the results of a linear probability model, a conditional logit model and a random effects probit model for exuberance on a 10% significance level, with a crisis dummy. Table 12 contains the results of a linear probability model, a conditional logit model and a random effects probit model for exuberance on a 1% significance level, with a crisis dummy. Finally, Table 13 shows the results if we include a time-response function in anticipation of QE (between August 2014 and December 2014).

Table 7: EXUBERANCE ON A 5% SIGNIFICANCE LEVEL, ALTERNATIVE MODELS WITHOUT CRISIS DUMMY

	1	2	3	4	5	6
	Linear probability model		*Conditional logit*		*Random effects probit*	
	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE
Yield10Y	-0.0708	-0.0541	-0.9775***	-0.6558*	-0.3989**	-0.2700
	(0.0412)	(0.0372)	(0.3790)	(0.3892)	(0.2029)	(0.1890)
Volatility	0.0969*	0.0821	0.8516**	0.8741**	0.5350***	0.5525**
.	(0.0493)	(0.0464)	(0.3776)	(0.4112)	(0.1941)	(0.2229)
Volume	0.0122	0.0382	0.0013	0.2606	-0.0735	0.0279
	(0.0837)	(0.0806)	(0.4934)	(0.5283)	(0.2040)	(0.2780)
Unempl.	0.1253	0.1371	0.5992	0.8540	0.3336	0.4480
	(0.1248)	(0.1078)	(0.8239)	(0.6997)	(0.4339)	(0.3469)
Ind. Prod.	-0.0073	-0.0067	-0.0518	-0.0503	-0.0261	-0.0248
	(0.0069)	(0.0066)	(0.0453)	(0.0456)	(0.0232)	(0.0214)
GDP	0.0128*	0.0049	0.0620	0.0129	0.0492	0.0190
	(0.0058)	(0.0081)	(0.0549)	(0.0666)	(0.0310)	(0.0383)
CNF	0.0043	0.0043	0.0257	0.0276	0.0146	0.0123
	(0.0055)	(0.0065)	(0.0357)	(0.0357)	(0.0201)	(0.0208)
SSR	0.0273	0.0661**	0.4025**	0.6533***	0.1616*	0.3230***
	(0.0190)	(0.0224)	(0.1738)	(0.1592)	(0.0929)	(0.0888)
QE1		0.3502**		3.0511***		1.7359***
		(0.1398)		(1.1648)		(0.6116)
QE2		0.3587**		3.2436***		1.8249***
		(0.1539)		(1.1814)		(0.6454)
QE3		0.2982*		2.4802**		1.3730**
		(0.1523)		(1.0638)		(0.5926)
QE4		0.1963		16.892		0.9196
		(0.1364)		(1.1133)		(0.6034)
QE5		0.0443		0.3239		0.1575
		(0.0644)		(0.7602)		(0.3981)
QE6		0.1844*		1.8175*		0.9649*
		(0.0943)		(1.0190)		(0.5510)
QE7		0.4101***		3.5547***		1.9608***
		(0.1000)		(1..415)		(0.5349)
Fixed effects	Yes	Yes	Yes	Yes	No	No
Time effects	No	No	No	No	No	No
Crisis dummy	No	No	No	No	No	No
N	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 5% significance level. Column 1 and 2 report a linear probability model with fixed effects. The results in columns 3 and 4 are based on a conditional logit analysis, column 5 and 6 on a random effects probit. The fixed effects in the conditional logit analysis come forward in the likelihood function. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. Period November 2007 - May 2018.

Table 8: EXUBERANCE ON A 5% SIGNIFICANCE LEVEL, ALTERNATIVE MODELS WITH CRISIS DUMMY

	1	2	3	4	5	6
	Linear probability model		*Conditional logit*		*Random effects probit*	
	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE
Yield10Y	-0.0344	-0.0312	-0.7678	-0.5389	-0.2425	-0.1685
	(0.0363)	(0.0351)	(0.4903)	(0.4495)	(0.1993)	(0.1862)
Volatility	0.0107	0.016	0.2102	0.308	0.1478	0.2059
	(0.0524)	(0.0518)	(0.3805)	(0.4425)	(0.2015)	(0.2351)
Volume	0.0147	0.0275	-0.111	0.066	-0.1082	-0.0509
	(0.0703)	(0.0718)	(0.5174)	(0.5296)	(0.1591)	(0.209)
Unempl.	0.1067	0.1205	0.4277	0.6352	0.2262	0.3094
	(0.0927)	(0.0882)	(0.7257)	(0.6271)	(0.3491)	(0.282)
Ind. Prod.	-0.0039	-0.0043	-0.0326	-0.0352	-0.0143	-0.0153
	(0.0056)	(0.0056)	(0.0427)	(0.0451)	(0.0209)	(0.0211)
GDP	0.0179***	0.0124	0.128	0.0901	0.0887**	0.0661
	(0.0047)	(0.0068)	(0.0835)	(0.0845)	(0.0441)	(0.0472)
CNF	-0.0003	0.0003	-0.0139	-0.0088	-0.0076	-0.0071
	(0.0046)	(0.0055)	(0.0496)	(0.0606)	(0.0255)	(0.0299)
SSR	-0.019	0.0111	-0.0232	0.1949	-0.0863	0.0534
	(0.0156)	(0.0173)	(0.1918)	(0.1491)	(0.0801)	(0.073)
QE1		0.2414		2.3582**		1.3542**
		(0.1364)		(1.052)		(0.5716)
QE2		0.2207		2.3176**		1.3171**
		(0.1506)		(1.1197)		(0.6293)
QE3		0.232		2.2337**		1.2390**
		(0.1493)		(1.0655)		(0.6168)
QE4		0.173		17.788		0.9851
		(0.1401)		(1.1607)		(0.6468)
QE5		0.002		-0.0233		-0.0011
		(0.0659)		(0.7426)		(0.4794)
QE6		0.0767		0.9817		0.52
		(0.088)		(1.0332)		(0.6008)
QE7		0.2225**		2.2539**		1.2159**
		(0.0901)		(1.0988)		(0.5659)
Fixed effects	Yes	Yes	Yes	Yes	No	No
Time effects	No	No	No	No	No	No
Crisis dummy	Yes	Yes	Yes	Yes	Yes	Yes
N	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 5% significance level. Column 1 and 2 report a linear probability model with fixed effects. The results in columns 3 and 4 are based on a conditional logit analysis, column 5 and 6 on a random effects probit. The fixed effects in the conditional logit analysis come forward in the likelihood function. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. Period November 2007 - May 2018.

Table 9: EXUBERANCE ON A 10% SIGNIFICANCE LEVEL IN A DYNAMIC PROBIT ANALYSIS

	1	2	3	4	5	6	7	8
	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE
Lagged bubble	2.5799***	2.4963***	2.4243***	2.4239***	2.5988***	2.5172***	2.4449***	2.4455***
	(0.1571)	(0.1677)	(0.1726)	(0.2166)	(0.1549)	(0.1628)	(0.1694)	(0.3591)
Yield10Y	-0.0825	-0.0435	-0.014	0.0043	-0.0811	-0.0409	-0.0121	0.0075
	(0.078)	(0.085)	(0.0823)	(0.0837)	(0.0777)	(0.085)	(0.0817)	(0.0917)
Volatility	-0.0351	-0.0341	-0.2881	-0.2641	-0.0251	-0.0209	-0.2765	-0.2495
	(0.1603)	(0.1721)	(0.1802)	(0.2009)	(0.1609)	(0.1739)	(0.1766)	(0.2093)
Volume	-0.0666	-0.0364	-0.0451	-0.0318	-0.0755	-0.0487	-0.0539	-0.0429
	(0.2328)	(0.2494)	(0.2235)	(0.2376)	(0.2339)	(0.251)	(0.2244)	(0.2432)
Unempl.	-0.0268	0.0173	0.034	0.0919	-0.0174	0.0433	0.0451	0.1186
	(0.3536)	(0.3763)	(0.3476)	(0.3863)	(0.3597)	(0.3817)	(0.3404)	(0.6024)
Ind. Prod.	0.0033	0.0031	0.0094	0.0078	0.0032	0.0028	0.0096	0.0079
	(0.0119)	(0.0111)	(0.0108)	(0.0107)	(0.0124)	(0.0121)	(0.0111)	(0.0114)
GDP	0.0694***	0.0295*	0.0384**	0.0202	0.0703***	0.0305**	0.0387**	0.0212
	(0.0182)	(0.0152)	(0.0179)	(0.0165)	(0.019)	(0.0154)	(0.0185)	(0.0333)
CNF	0.0366	0.0083	0.0168	-0.0027	0.0349	0.0046	0.0151	-0.0058
	(0.0451)	(0.0404)	(0.0443)	(0.033)	(0.0451)	(0.04)	(0.0452)	(0.0326)
SSR	0.0594**	0.1825***	-0.0906**	0.003	0.0583**	0.1842***	-0.0926**	0.0037
	(0.0288)	(0.0343)	(0.0375)	(0.0405)	(0.0285)	(0.0338)	(0.037)	(0.0505)
QE1		2.0672***		1.6742***		2.1127***		1.7163**
		(0.388)		(0.4805)		(0.3937)		(0.7045)
QE2		0.7196*		0.3194		0.7183*		0.3247
		(0.434)		(0.4749)		(0.4175)		(0.7217)
QE3		0.4731		0.3368		0.4607		0.3207
		(0.3777)		(0.3771)		(0.4049)		(0.3986)
QE4		0.2666		0.306		0.3056		0.3377
		(0.393)		(0.3746)		(0.3513)		(0.3296)
QE5		0.4433		0.3403		0.4717		0.3683
		(0.3323)		(0.2911)		(0.3605)		(0.498)
QE6		0.1631		-0.1098		0.1498		-0.1215
		(0.2905)		(0.3038)		(0.2985)		(0.5434)
QE7		1.2404***		0.6611*		1.2660***		0.6819
		(0.2609)		(0.3386)		(0.2617)		(0.568)
Fixed effects	No	No	No	No	Yes	Yes	No	No
Time effects	No	No	No	No	No	No	Yes	Yes
Crisis dummy	No	No	Yes	Yes	No	No	Yes	Yes
N	1260	1260	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 10% significance level. Column 5-8 contain time effects, column 3, 4, 7 and 8 contain crisis dummies. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. For time effects a monthly dummy is used, while the crisis dummy is 1 during 2008 and 2009, 0 otherwise. Volatility and Volume are in logs, unemployment rate, industrial production and real GDP in monthly growth rates. CNF refers to Credit to the Non-Financial sector as % of GDP and is also taken as a monthly change. Period November 2007 - May 2018.

Table 10: EXUBERANCE ON A 1% SIGNIFICANCE LEVEL IN A DYNAMIC PROBIT ANALYSIS

	1 Without QE	2 Incl. QE	3 Without QE	4 Incl. QE	5 Without QE	6 Incl. QE	7 Without QE	8 Incl. QE
Lagged bubble	2.2471***	2.2008	2.139	2.1094	2.3105***	2.2625	2.2016	2.1711
	(0.5511)	(3.3154)	(11.4295)	(24.4458)	(0.5594)	(1.4973)	(8.0138)	(19.8956)
Yield10Y	-0.2652	-0.2049	-0.1711	-0.1451	-0.2759	-0.2121	-0.1846	-0.1569
	(0.1818)	(1.4789)	(3.9342)	(10.4825)	(0.1973)	(0.6563)	(2.9155)	(9.0321)
Volatility	0.2679	0.3219	0.0327	0.0928	0.2356	0.2921	0.0023	0.0633
	(0.2541)	(0.8054)	(4.8669)	(16.1726)	(0.2448)	(0.564)	(3.6017)	(17.0354)
Volume	0.0279	0.0418	-0.0152	-0.034	0.0356	0.05	-0.0044	-0.0251
	(0.1708)	(0.3047)	(0.4977)	(1.2102)	(0.1707)	(0.1683)	(0.4959)	(1.7576)
Unempl.	-0.0443	-0.0759	-0.2221	-0.2134	-0.0503	-0.0705	-0.2359	-0.2126
	(0.5168)	(3.5605)	(1.2579)	(31.8332)	(0.5026)	(1.7708)	(8.2967)	(22.6475)
Ind. Prod.	-0.0093	-0.0073	-0.0032	-0.0027	-0.0092	-0.0071	-0.0029	-0.0019
	(0.0127)	(0.0542)	(0.1062)	(0.2369)	(0.0129)	(0.0217)	(0.0902)	(0.2296)
GDP	0.0473*	0.0402	0.0719	0.0723	0.0498**	0.0414	0.0735	0.0724
	(0.0256)	(0.0355)	(0.1879)	(0.9854)	(0.0245)	(0.0263)	(0.1396)	(1.0304)
CNF	0.0437	0.0171	0.0419	0.0124	0.056	0.0241	0.0542	0.0186
	(0.0476)	(0.2628)	(0.8481)	(24.784)	(0.0538)	(0.12)	(0.5197)	(18.144)
SSR	0.1278*	0.1676	-0.018	-0.0007	0.1320*	0.1711	-0.0126	0.0028
	(0.0692)	(0.394)	(18.906)	(38.368)	(0.0732)	(0.1445)	(13.701)	(29.905)
QE1		1.084		0.8466		1.1696		0.9208
		(1.3486)		(7.4238)		(0.8328)		(8.6214)
QE2		0.959		0.6899		0.9233*		0.663
		(1.5469)		(8.8327)		(0.5402)		(1.7626)
QE3		-0.2521		-0.3726		-0.287		-0.429
		(4.5485)		(39.5359)		(2.4817)		(35.5353)
QE4		0.1915		0.2359		0.2848		0.3257
		(2.7845)		(27.0363)		(1.4678)		(25.4271)
QE5		-0.4104		-0.625		-0.3724		-0.5918
		(3.126)		(34.4853)		(1.2443)		(23.7997)
QE6		-0.1517		-0.6084		-0.1746		-0.5942
		(2.4932)		(2.3437)		(1.5615)		(25.2097)
QE7		0.5315		0.095		0.5254		0.0824
		(1.6786)		(8.1667)		(1.0227)		(7.525)
Fixed effects	No	No	No	No	Yes	Yes	No	No
Time effects	No	No	No	No	No	No	Yes	Yes
Crisis dummy	No	No	Yes	Yes	No	No	Yes	Yes
N	1260	1260	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 1% significance level. Column 5-8 contain time effects, column 3, 4, 7 and 8 contain crisis dummies. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. For time effects a monthly dummy is used, while the crisis dummy is 1 during 2008 and 2009, 0 otherwise. Volatility and Volume are in logs, unemployment rate, industrial production and real GDP in monthly growth rates. CNF refers to Credit to the Non-Financial sector as % of GDP and is also taken as a monthly change. Period November 2007 - May 2018.

Table 11: EXUBERANCE ON A 10% SIGNIFICANCE LEVEL, ALTERNATIVE MODELS WITH CRISIS DUMMY

	1	2	3	4	5	6
	Linear probability model		*Conditional logit*		*Random effects probit*	
	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE
Yield10Y	-0.0518	-0.0471	-0.6266	-0.4776	-0.1633	-0.1198
	(0.0416)	(0.0406)	(0.4683)	(0.4519)	(0.1679)	(0.1669)
Volatility	-0.0329	-0.0228	-0.2218	-0.1407	-0.1003	-0.051
	(0.0632)	(0.0617)	(0.3773)	(0.4236)	(0.1993)	(0.2313)
Volume	-0.0428	-0.0277	-0.3485	-0.2249	-0.1765	-0.1334
	(0.0978)	(0.1009)	(0.5157)	(0.5682)	(0.198)	(0.2411)
Unempl.	0.0895	0.1039	0.2787	0.4777	0.2312	0.334
	(0.0916)	(0.0937)	(0.6391)	(0.6132)	(0.3512)	(0.3345)
Ind. Prod.	-0.005	-0.0054	-0.0395	-0.0398	-0.0186	-0.019
	(0.0041)	(0.0042)	(0.0272)	(0.0275)	(0.014)	(0.014)
GDP	0.0164***	0.0083	0.0937	0.0414	0.0648*	0.035
	(0.0041)	(0.0063)	(0.0574)	(0.0625)	(0.034)	(0.0415)
CNF	0.0014	-0.0004	0.0231	0.012	0.0125	0.0066
	(0.0051)	(0.0064)	(0.0488)	(0.0582)	(0.0253)	(0.0315)
SSR	-0.0198	0.0227	-0.0565	0.2026	-0.1145*	0.0533
	(0.0177)	(0.0181)	(0.1668)	(0.1308)	(0.0616)	(0.068)
QE1		0.4203**		2.8079***		1.6643***
		(0.1484)		(0.9787)		(0.5355)
QE2		0.3947*		2.7631**		1.6458***
		(0.1782)		(1.094)		(0.6183)
QE3		0.244		1.9205*		1.1453**
		(0.1584)		(0.9852)		(0.5761)
QE4		0.1946		1.5507*		0.9464*
		(0.1307)		(0.7984)		(0.4895)
QE5		0.0379		0.2893		0.2252
		(0.1103)		(1.1007)		(0.6062)
QE6		0.0912		0.8203		0.4976
		(0.0889)		(0.7906)		(0.4786)
QE7		0.3057**		2.2579**		1.2819**
		(0.1124)		(0.968)		(0.5191)
Fixed effects	Yes	Yes	Yes	Yes	No	No
Time effects	No	No	No	No	No	No
Crisis dummy	Yes	Yes	Yes	Yes	Yes	Yes
N	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 10% significance level. Column 1 and 2 report a linear probability model with fixed effects. The results in columns 3 and 4 are based on a conditional logit analysis, column 5 and 6 on a random effects probit. The fixed effects in the conditional logit analysis come forward in the likelihood function. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. For time effects a monthly dummy is used, while the crisis dummy is 1 during 2008 and 2009, 0 otherwise. Volatility and Volume are in logs, unemployment rate, industrial production and real GDP in monthly growth rates. CNF refers to Credit to the Non-Financial sector as% of GDP and is also taken as a monthly change. Period November 2007 - May 2018.

Table 12: EXUBERANCE ON A 1% SIGNIFICANCE LEVEL, ALTERNATIVE MODELS WITH CRISIS DUMMY

	1	2	3	4	5	6
	Linear probability model		*Conditional logit*		*Random effects probit*	
	Without QE	Incl. QE	Without QE	Incl. QE	Without QE	Incl. QE
Yield10Y	-0.0191	-0.0178	-0.7506***	-0.6398***	-0.3487**	-0.2998**
	(0.0244)	(0.0248)	(0.2364)	(0.1754)	(0.1439)	(0.1172)
Volatility	0.0073	0.0102	0.2807	0.466	0.1659	0.2443
	(0.0361)	(0.0334)	(0.5636)	(0.522)	(0.2927)	(0.2531)
Volume	0.0138	0.0106	-0.2227	-0.2317	-0.0833	-0.0882
	(0.0238)	(0.0242)	(0.2855)	(0.2807)	(0.0878)	(0.0935)
Unempl.	0.0814	0.083	0.3999	0.4696	0.1675	0.1744
	(0.0768)	(0.0781)	(0.7984)	(0.8412)	(0.3774)	(0.3917)
Ind. Prod.	0.0001	0.0003	0.0016	0.0018	-0.0002	0.0005
	(0.0036)	(0.0035)	(0.0359)	(0.0387)	(0.0193)	(0.0194)
GDP	0.0215**	0.0206**	0.1895***	0.2059***	0.1003***	0.1055***
	(0.0076)	(0.0074)	(0.0613)	(0.0562)	(0.0381)	(0.0391)
CNF	0.0022	-0.0004	0.0088	-0.0356	0.0094	-0.0138
	(0.0052)	(0.0051)	(0.0682)	(0.0844)	(0.0315)	(0.035)
SSR	-0.0038	-0.0014	0.0751	0.121	0.0257	0.0515
	(0.0098)	(0.0144)	(0.0687)	(0.1698)	(0.0431)	(0.0925)
QE1		0.1318		1.9572***		1.0012***
		(0.0886)		(0.5152)		(0.3138)
QE2		0.1608		2.3109**		1.1902**
		(0.1212)		(0.9049)		(0.5173)
QE3		0.0282		0.376		0.187
		(0.0473)		(0.6468)		(0.3836)
QE4		0.0278		0.3401		0.1602
		(0.0422)		(0.5875)		(0.2811)
QE5		-0.0457		-2.0251**		-0.9155**
		(0.0454)		(0.8061)		(0.4584)
QE6		-0.0345		-1.7692**		-0.7913*
		(0.0374)		(0.7741)		(0.4527)
QE7		0.0089		0.4444		0.2048
		(0.0708)		-12.664		(0.6552)
Fixed effects	Yes	Yes	Yes	Yes	No	No
Time effects	No	No	No	No	No	No
Crisis dummy	Yes	Yes	Yes	Yes	Yes	Yes
N	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 1% significance level. Column 1 and 2 report a linear probability model with fixed effects. The results in columns 3 and 4 are based on a conditional logit analysis, column 5 and 6 on a random effects probit. The fixed effects in the conditional logit analysis come forward in the likelihood function. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. For time effects a monthly dummy is used, while the crisis dummy is 1 during 2008 and 2009, 0 otherwise. Volatility and Volume are in logs, unemployment rate, industrial production and real GDP in monthly growth rates. CNF refers to Credit to the Non-Financial sector as % of GDP and is also taken as a monthly change. Period November 2007 - May 2018.

Table 13: EXUBERANCE ON A 5% SIGNIFICANCE LEVEL IN A DYNAMIC PROBIT ANALYSIS WITH ANTICIPATION EFFECT OF QE (QE0, AUG 2014 - DEC 2014)

	1 Without QE	2 Incl. QE	3 Without QE	4 Incl. QE	5 Without QE	6 Incl. QE	7 Without QE	8 Incl. QE
Lagged Bubble	2.3478***	2.1901***	2.1538***	2.0934***	2.4052***	2.2416***	2.2072***	2.1438***
	(0.2039)	(0.1621)	(0.1413)	(0.1426)	(0.2113)	(0.1717)	(0.1543)	(0.1563)
Yield10Y	-0.1583	-0.0318	-0.0686	0.0218	-0.1633	-0.0352	-0.0749	0.0181
	(0.1124)	(0.0906)	(0.1119)	(0.0962)	(0.1120)	(0.0912)	(0.1112)	(0.0970)
Volatility	0.2447	0.2623	0.0037	0.0423	0.2557	0.2752	0.0172	0.0560
	(0.1636)	(0.1800)	(0.1410)	(0.1854)	(0.1632)	(0.1828)	(0.1407)	(0.1881)
Volume	-0.0587	0.0381	-0.0492	0.0148	-0.0578	0.0346	-0.0500	0.0091
	(0.1632)	(0.1850)	(0.1463)	(0.1674)	(0.1705)	(0.1894)	(0.1547)	(0.1728)
Unempl.	0.1633	0.2387	0.1301	0.1917	0.1689	0.2597	0.1328	0.2081
	(0.3181)	(0.2807)	(0.3270)	(0.2770)	(0.3159)	(0.2748)	(0.3245)	(0.2629)
Ind. Prod.	0.0138	0.0085	0.0182	0.0136	0.0135	0.0070	0.0182	0.0127
	(0.0220)	(0.0205)	(0.0196)	(0.0196)	(0.0219)	(0.0201)	(0.0200)	(0.0198)
GDP	0.0728***	0.0238	0.0660***	0.0344	0.0730***	0.0236	0.0662***	0.0349
	(0.0210)	(0.0163)	(0.0253)	(0.0264)	(0.0229)	(0.0164)	(0.0253)	(0.0258)
CNF	0.0067	-0.0102	-0.0119	-0.0214	0.0048	-0.0132	-0.0134	-0.0240
	(0.0322)	(0.0243)	(0.0297)	(0.0265)	(0.0372)	(0.0277)	(0.0327)	(0.0297)
SSR	0.0898*	0.2471***	-0.0768	0.0729**	0.0927*	0.2519***	-0.0744	0.0761**
	(0.0534)	(0.0403)	(0.0478)	(0.0303)	(0.0526)	(0.0403)	(0.0486)	(0.0320)
QE0		1.3485***		1.1345***		1.3881***		1.1737***
		(0.2181)		(0.2167)		(0.2393)		(0.2323)
QE1		2.1494***		1.8454***		2.1880***		1.8790***
		(0.5092)		(0.5161)		(0.5086)		(0.5178)
QE2		1.4770***		1.1411***		1.5061***		1.1591***
		(0.3652)		(0.3688)		(0.3337)		(0.3425)
QE3		1.2849***		1.1951***		1.3108***		1.2185***
		(0.3429)		(0.3667)		(0.3763)		(0.3999)
QE4		0.9027		0.9560		0.9289*		0.9766*
		(0.5942)		(0.6160)		(0.5410)		(0.5643)
QE5		0.7381*		0.6719		0.7978**		0.7246**
		(0.4407)		(0.4460)		(0.3612)		(0.3664)
QE6		0.9624*		0.7072		1.0082*		0.7504
		(0.5086)		(0.5279)		(0.5341)		(0.5416)
QE7		1.8473***		1.3653***		1.8646***		1.3779***
		(0.3208)		(0.3417)		(0.3246)		(0.3407)
Fixed effects	No	No	No	No	No	No	No	No
Time effects	No	No	No	No	Yes	Yes	Yes	Yes
Crisis dummy	No	No	Yes	Yes	No	No	Yes	Yes
N	1260	1260	1260	1260	1260	1260	1260	1260

Note: Dependent variable: binary, 1 if there is exuberance on the basis of BSADF, 0 otherwise. Exuberance is determined on a 5% significance level. Column 5-8 contain time effects, column 3, 4, 7 and 8 contain crisis dummies. The even columns contain dummy variables that capture two monthly dynamic time effects since January 2015 (Response 1-6) and a dummy that captures the remaining part of the time effects after December 2015 (Response 7). QE0 captures the time-response function in anticipation of QE (between Aug 2014 and Dec 2014). Standard errors (clustered at the country level) are reported in parentheses. *, ** and *** indicate significance at 10%, 5% and 1%, respectively. For time effects a monthly dummy is used, while the crisis dummy is 1 during 2008 and 2009, 0 otherwise. Volatility and Volume are in logs, unemployment rate, industrial production and real GDP in monthly growth rates. CNF refers to Credit to the Non-Financial sector as % of GDP and is also taken as a monthly change. Period November 2007 - May 2018.

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