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ASSET PRICE VOLATILITY IN EU-6 ECONOMIES: HOW LARGE IS THE ROLE PLAYED BY THE ECB?

by Alessio Ciarlone* and Andrea Colabella*

Abstract

In this paper we provide evidence that the effects of the different waves of asset purchase programmes implemented by the ECB from 2009 onwards have spilled over into asset price volatility developments of a group of six Central and Eastern European economies belonging to the EU but not to the euro area. This has partly shielded their financial markets from the negative shocks that have influenced international investors' degree of risk aversion in recent years. By means of a dynamic conditional correlation multivariate GARCH model, and by resorting to three different proxies to describe the functioning and measure the impact of the ECB's asset purchase programmes, we show that such non-standard monetary measures have played a significant role in dampening volatility spikes in the financial markets of the countries at stake. This probably reflects how both a 'risk taking' and a 'liquidity' channel of transmission actually work. The results are generally robust to an extensive series of tests, and to changes made in the estimation methodology.

JEL Classification: C32, E52, E58, F3, F4, F16, F37, G1, G11, G14.
Keywords: unconventional monetary policy, ECB, Central and Eastern Europe, international spillovers, asset prices, volatility, GARCH models.

Contents

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1. Introduction and main conclusions[1]

Over the last decade, central banks around the world have embarked on an unprecedented effort to tackle the negative consequences of the string of adverse shocks that hit the global economy: they not only slashed reference rates to historical lows but also launched innovative 'unconventional' tools, among which the so-called 'quantitative' and 'credit easing' programmes prominently stood out. Like other central banks in advanced economies (AEs), the European Central Bank (ECB) resorted to a series of non-standard monetary measures as well, aimed to cope with a variety of unusual risks that the euro area has been facing in recent years including liquidity disturbances in certain financial markets, fears of a euro break-up and the ensuing 'redenomination risk' and, more recently, a prolonged period of excessively low inflation. Among such non-standard measures, asset purchase programmes (APPs) have increasingly gained in importance and, as of late 2016, ended up accounting for around 45% of total assets in the Eurosystem's balance sheet.

An ample literature has investigated the international spillover effects, and the related transmission channels, of such unconventional monetary policies with regard to the experience of both the Federal Reserve (Chen *et al.*, 2012; Ahmed and Zlate, 2014; Bowman *et al.*, 2015, just to name a few) and the ECB (Falagiarda *et al.*, 2015; Georgiadis and Gräb, 2015; Ciarlone and Colabella, 2016). These studies mainly paid attention to the cross-border impact of unconventional monetary policies on the *level* of both financial and real variables in emerging market economies (EMEs). Only very recently has the focus begun to shift to analysing the consequences of such monetary policy measures on the *volatility* of both real and financial variables, at home as well as abroad, hence focusing on 'volatility spillovers' in the words of Apostolou and Beirne (2017).

The aim of this paper is to contribute to this relatively new strand of literature. In particular, we intend to gauge whether and to what extent the implementation of the APPs by the ECB might have played a role in shielding financial markets in six Central and Eastern European economies belonging to the European Union but not to the euro area (the EU-6) from adverse external shocks to international investors' degree of risk aversion.[2] As these countries are deeply integrated with the euro area through strong financial linkages – the euro area is the source of large capital flows towards them, while their domestic banking systems are largely dominated by euro area banking groups – there are good reasons to suspect that their equity, long-term government bond and foreign exchange markets may be subject to volatility spillovers stemming from the ECB's APPs.

We try to answer to this research question by means of the econometric approach contained in Ananchotikul and Zhang (2014), which is based upon the estimation of separate country-specific Dynamic Conditional Correlation Multivariate GARCH (DCC-MGARCH) models on the series of the *levels* of asset returns of the three markets at stake. Such models have been shown to be able to usefully take on board asset return volatility clustering while allowing for relationships between the volatility processes of the asset markets at stake which, in turn, captures important cross-market spillover effects. While taking into account developments in global volatility, attention is focused on a series of proxies – traditionally used in the extant literature to describe the functioning, and measure the impact, of the ECB's APPs – to gauge the spillovers of such non-standard measures on volatility developments in EU-6 financial markets: namely, the increase in the ECB's security holdings for monetary purposes, the weekly average of the euro area AAA-rated government bond yields and the weekly average of the Wu and Xia (2016) shadow rate calculated for the euro area. Being aware that

[1] We thank two anonymous referees, Giuseppe Parigi, Pietro Catte, Giorgio Merlonghi, Emidio Cocozza for their helpful comments and suggestions on earlier versions of the paper. The usual disclaimers apply.

[2] The aggregate EU-6 includes Bulgaria, Croatia, the Czech Republic, Hungary, Poland and Romania.

both the latter interest rates could have been affected by several other factors in addition to the direct impact of the ECB's APPs, we factor in this consideration by using two refinements. As for the euro area AAA-rated government bond yields, we resort to the two-stage procedure originally proposed by Ahmed and Zlate (2014), which is intended to isolate the changes in long-term yields that can be considered as directly attributable to the implementation of the programmes of asset purchases. As for the shadow rate, we augment the basic specification with a couple of additive and interaction dummies to look at whether the fall of the shadow rate into negative territories in December 2011 – traditionally considered in the existing literature as a reflection of the implementation of unconventional monetary policies – may have altered the impact of our proxy on volatility developments in EU-6 financial markets.

Overall, estimation results about the sign and the statistical and economic significance of the proposed three proxies clearly point to the conclusion that the implementation of the different waves of the ECB's APPs was able to shield EU-6 financial markets from the impact of negative external shocks to international investors' degree of risk aversion. We relate this taming impact to the working of a "risk-taking" and a "liquidity" channel of transmission related to the highly accommodative non-standard monetary policies implemented by the ECB, originally put forward by Borio and Zhu (2012) and empirically confirmed by Bakeart *et al.* (2013) and Bruno and Shin (2015). These conclusions seem to be valid against a large series of robustness tests based on alternative model specifications and econometric procedures. In a monetary policy perspective, such results have important implications: in fact, looking forward, it cannot be ruled out that the process of gradual re-calibration of the monetary stance by the ECB could be accompanied by an increase in volatility in EU-6 financial markets.

We contribute to the existing literature along several dimensions. First of all, we provide new insights to the nascent debate about the spillovers triggered by unconventional monetary measures implemented by AEs central banks onto volatility developments in EMEs financial markets which, to the best of our knowledge, has appeared only in a limited number of studies up to date. Second, we rely upon an econometric technique (the DCC-MGARCH) which is able to adequately take on board both volatility clustering and important cross-market correlations while allowing, at the same time, a sufficient degree of flexibility in the estimation procedure and a relatively light computational burden. Third, we analyse volatility spillovers by resorting to a wide set of proxies which are adequately "treated" to describe, as far as possible, the actual impact of the ECB's non-standard monetary policies. Fourth, the estimation exercise is also performed on a rather long time span, ranging from January 2007 to December 2016, which enables us not only to obtain more reliable and accurate estimates of the different linkages underlying the chosen variables, but also to study the whole period throughout which the ECB implemented different waves of APPs comprising the "expanded" one enacted by end-2014.[3] Finally, we focus on financial markets only – which are supposed to bear the brunt of volatility changes – and on a narrow set of countries – the EU-6 economies, in light of their strong financial linkages with the euro area: we retain that both of these choices would help us to better figure out the existence, and the extent, of the volatility spillovers stemming from the implementation of the ECB's non-standard monetary policies.

The paper is structured as follows. After reporting brief stylized facts about the ECB's APPs (Section 2), we quickly review the existing literature related to volatility spillovers from advanced to emerging economies and sketch the channels of transmission that may be at play when highly accommodative monetary policies are explicitly taken into account (Section 3). Section 4 describes the

[3] The ECB launched the first of its APPs programmes in May 2009, with actual purchases beginning in the following month. See below for greater detail.

key technical features of the DCC-MGARCH procedure and then offers evidence of the favourable role played by the ECB's APPs in containing volatility spikes in EU-6 economies financial markets. After confirming that these results are robust against an extensive set of tests (Section 5), conclusions and policy implications are finally drawn (Section 6).

2. Stylised facts on ECB's APPs

Since mid-2009, the ECB has implemented a number of APPs as part of its non-standard monetary policy toolkit, with a view to dealing with the emergence of unprecedented problems and risks. The Enhanced Credit Support (ECS), officially launched in May 2009, contained the first programme of outright asset purchases – the Covered Bond Purchase Programme (CBPP1) – with the explicit goal of rekindling the functioning of the covered bond market, an essential source of refinancing for euro area banks. This programme was subsequently renewed twice, first in November 2011 (CBPP2) and then in October 2014 (CBPP3).

In May 2010, as tensions on the sovereign debt markets of certain euro area countries emerged, the ECB introduced an additional APP – the Securities Market Programme (SMP) – which involved purchases of euro area government bonds to ensure adequate depth and liquidity in secondary markets.[4]

In July 2012, at the height of the European sovereign debt crisis, President Draghi's 'whatever it takes' speech in London paved the way for the adoption, in September 2012, of the Outright Monetary Transactions (OMT) initiative.[5] The declared objective of the OMT was to safeguard '(…) an appropriate monetary policy transmission and the singleness of the monetary policy (…)' by lowering bond yields – whose high level was deemed to be unjustified if compared with the value implied by fundamentals (see for example, Di Cesare *et al.,* 2012) – especially at the long-end of the curve, thus reducing borrowing costs and preserving investors' confidence in the stability and smooth functioning of the sovereign bond markets. The OMT was intended to overcome monetary and financial fragmentation in the euro area by removing the redenomination risk related to its possible breakup. It is worth recalling that the OMT has never been implemented.

In June 2014, with the explicit aim to revive bank lending to the euro area's non-financial private sector, a broad credit easing package was announced. The package included, among other things, intensifying preparatory work related to the outright purchase of asset-backed securities (ABSPP), which eventually started in October 2014 in parallel with the launch of the third wave of the CBPP.

In January 2015, the Governing Council announced a purchase programme for public sector securities (PSPP) which, together with the existing programmes (CBPP3 and ABSPP) under the new headings of Expanded Asset Purchase Programmes (EAPP), had the clear objective to address the risk of a too prolonged period of low inflation. Under the initial setup, the ECB expanded its purchases to include bonds issued by euro area central governments, agencies and European institutions, with

[4] SMP purchases were made in two big waves, one in the first half of 2010 and the other in the second half of 2011, with their liquidity impact sterilized through specific operations. The purchases were conducted on a discretionary basis, according to daily market conditions.

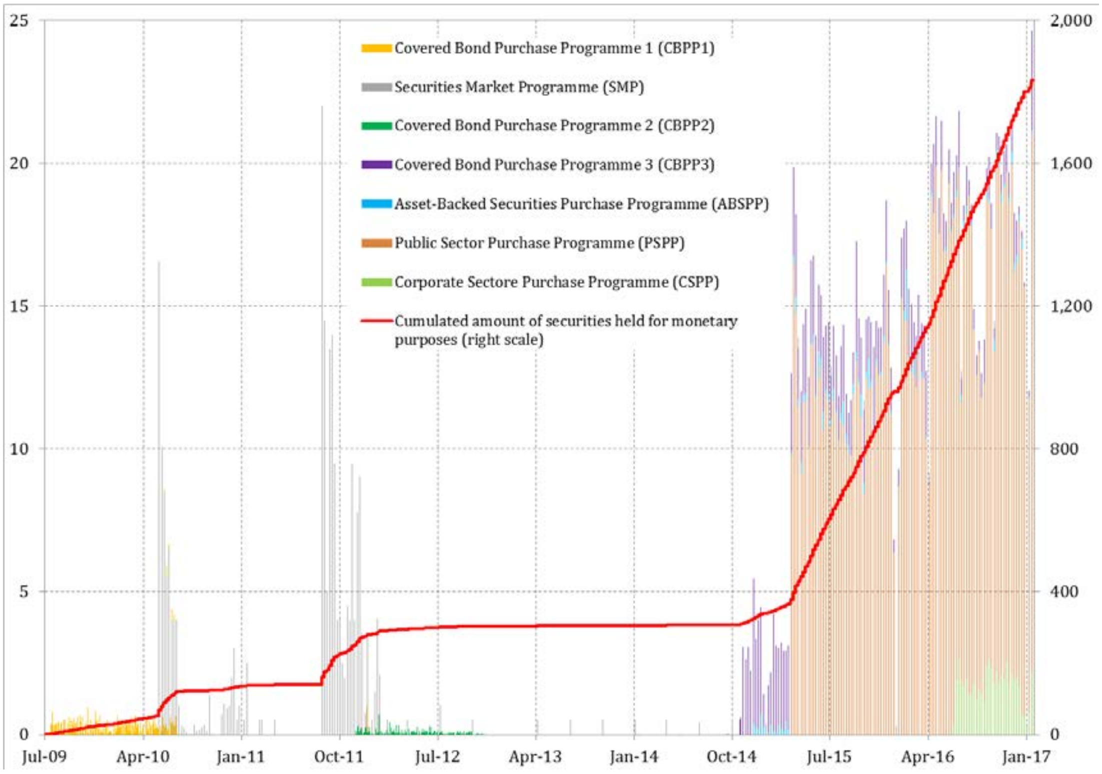
[5] Within this programme, the ECB could have purchased an unlimited amount of sovereign bonds maturing in 1-3 years on request by a government asking for financial assistance, provided that the bond-issuing country implemented specific measures (the conditionality principle) agreed under an adjustment programme to be signed with the European Financial Stability Facility (later the European Stability Mechanism).

combined monthly asset purchases to amount to €60 billion on average.[6] Later on, starting from June 2016, investment grade euro-denominated bonds issued by non-financial corporations established in the euro area were included in the list of eligible assets for regular purchases, i.e. the corporate sector purchase programme (CSPP).

In October 2017, the Governing Council decided to extend the purchases under the EAPP until September 2018 or beyond, if necessary, and, in any case, until the Governing Council sees a sustained adjustment in the path of inflation consistent with its inflation objective (i.e. a rate below, but close to, 2% over the medium-term). Starting from January 2018, moreover, the overall amount of monthly purchases would have been reduced to €30 billion monthly.[7]

The overall stock of securities purchased under all programmes increased steadily to 10% of the Eurosystem's total assets between 2009Q3 and 2010Q3, hovered around this level until the end of 2014 and then started ramping up again following the launch of the EAPP, to reach a share of almost 45% of total assets as of late-2016 (**Chart 1**).

Chart 1. Evolution of the ECB's asset purchase programmes, 2009 - 2016
(daily data, billions of euros)



Note: the chart shows the amounts of financial assets purchased on a weekly basis by the ECB since the summer of 2009 under the different programmes, as well as the cumulated stock of purchased assets held for monetary policy purposes.
Source: European Central Bank.

[6] This figure was subsequently raised to €80 billion with the April 2016 decision of the Governing Council and implemented up to March 2017, when the Governing Council decided to partially 'taper' the asset purchases by reducing the monthly figure back again to €60 billion.

[7] Originally, the EAPP program was meant to terminate in September 2016; the end of the programme was prolonged three times: i) in July 2016 to March 2017; iii) in December 2016 to December 2017; iii) in October 2017 to September 2018.

3. Related literature and main transmission channels

This paper lies at the juncture of two different strands of economic literature. On the one hand, it focuses on issues related to financial volatility spillovers from advanced to emerging economies; on the other hand, it deals with the analysis of those spillovers to EMEs which stem from the implementation of *unconventional* monetary policies by major central banks in AEs.

The issue of financial volatility spillovers between advanced and emerging economies has attracted increasing attention in the literature during recent years. Many authors looked at this issue using diverse econometric techniques, including VARs (Diebold and Yilmaz, 2009; Yilmaz, 2010; Diebold and Yilmaz, 2010; Singh and Kaur, 2016), DCC-MGARCH (Ananchotikul and Zhang, 2014) and a combination of VARs, DCC-MGARCH and 'heat map' models (Bianconi *et al.*, 2013). Even though these exercises were applied to various countries over different time periods, the presence of such positive volatility spillovers was consistently found out throughout all of them.

Since the outbreak of the global financial and euro area sovereign debt crises and the resulting slashing of official reference rates to the zero lower bound (ZLB), accompanied by the implementation of *unconventional* measures by major central banks in AEs, a growing strand of economic literature has focused on the national and international channels of transmission of such an unprecedented degree of monetary policy accommodation. In view of the aim of this paper, among the various channels proposed by the literature we deem it crucial to analyse the one that links financial market volatility to monetary policy.[8] In this regard, Borio and Zhu (2012) were the first to suggest the existence of a "risk-taking" channel of transmission, which relates to how the implementation of highly accommodative monetary policies – through both *conventional* and *unconventional* measures – are supposed to affect the perception and pricing of risk, as well as the degree of risk tolerance, of banks and other types of investors. Ideally, in fact, there is a number of ways through which ultra-low interest rates (independently of their underlying cause) can influence economic agents' risk-taking behaviour, i.e. through which the "risk-taking" channel may operate.

One set of effects operates through the impact of low interest rates on valuations, incomes, cash flows and the resulting measured risk: a reduction in policy rates, as well as the implementation of large scale asset purchase programmes, is typically supposed to generate a boost in asset and collateral values; in turn, the increase in the value of corporate equities relative to corporate debts may induce an overall re-evaluation of private investors' estimates of probabilities of defaults and losses-given-defaults; finally, a reduced risk perception (or an increased risk tolerance) is typically reflected into lower asset price volatilities throughout the different segments of the overall financial system.

A second set of effects operates through the "search for yield", which stems from the relationship between prevailing market rates and target rates of return (BIS, 2004; Rajan, 2005). A highly accommodative monetary stance may increase incentives for asset managers to take on more risk for a number of reasons. Some are psychological or behavioural in nature, such as difficulties in adjusting expectations following periods of exuberance in financial markets. Others may reflect institutional or regulatory constraints: the typical case is represented by the need for life insurance companies and pension funds to manage their assets in such a way as to be able to deal with expected liabilities which are linked to a minimum guaranteed nominal rate of return rather than the current (historically low)

[8] There is not enough space here to summarise the extensive literature on the international spillover effects on the *level* of both real and financial variables in EMEs stemming from the different rounds of quantitative easing measures implemented by major central banks in AEs. The interested reader is referred to Ciarlone and Colabella (2016) for a summary on the topic.

level of yields. In the same vein, financial institutions regularly enter into long-term contracts requiring them to produce relatively high nominal rates of return. The link between low interest rates and excessive risk-taking may also be influenced by competition, the structure of managerial bonus schemes and deficiencies in supervision and regulation, as well as by habit formation: an easing of monetary policy, by increasing expected real economic activity, may decrease the degree of investors' risk aversion because their expected consumption increases relatively to normal levels.

A third set of effects may operate through the communication policies of a central bank and the characteristics of policymakers' reaction functions. For example, a high degree of central bank predictability with regard to future policy decisions can reduce market uncertainty and thus lead banks and investors more broadly to take on more risks. In this way, agents' perception that the central bank will ease monetary policy in the event of bad economic outcome could lower the probability of large downside risks, thereby producing an insurance effect, a typical moral hazard problem.

These three sets of effect are intended to operate jointly.

While such a "risk-taking" channel can be activated by any type of monetary policy, it is more likely to come into play in the context of the non-standard measures such as those implemented by the ECB, as the ample liquidity poured into financial markets as a consequence of the different waves of asset purchase programmes may have had an important bearing on investors' behaviour as well as on financial markets volatility developments. In this regard, it is helpful to recall the definition of liquidity again suggested by Borio and Zhu (2012) as the ease with which perceptions of value can be turned into purchasing power. Thus, higher liquidity may translate into an increased ability of investors, on the one side, to meet both current and future cash flows and collateral needs – the "funding (cash) liquidity" in their words – and, on the other side, to trade an asset at short notice with little impact on its price in the context of their portfolio rebalancing strategies – the "market liquidity". Be as it may, both "funding (cash) liquidity" and "market liquidity" mechanisms contribute to smoothing out price valuation changes in financial markets and hence to softening volatility movements. Indeed, the two concepts of investors' risk-taking behaviour and (market or funding cash) liquidity display a high degree of interconnectedness and do reinforce each other (Borio and Zhu, 2012): on the one hand, lower perceptions of risk and greater risk tolerance weaken external funding and transferability constraints; on the other hand, weaker constraints can support higher risk-taking.

The underlying postulate to this theoretical reasoning is the existence of an inverse (i.e. negative) relationship between accommodative monetary policy and financial market volatility: against the background of a reduced risk perception (or an increased risk tolerance) amid abundant market and/or funding cash liquidity, international investors would tend to expand their cross-border exposures in a "risk-on", "search for yield", mood also on account of the perception that the Central bank would intervene further to cut off large downside risks.

From an empirical perspective, Bekaert *et al*. (2013) were the first to provide a characterisation of the dynamic links between risk, uncertainty and monetary policy using a simple vector-autoregressive framework. After splitting the traditional implied volatility VIX index into two components – risk aversion and uncertainty – the interactions between each of them and US monetary policy are studied under a variety of identification schemes for monetary policy shocks. According to their conclusions, it is consistently found that lax monetary policy in the US both increases risk appetite (i.e. decreases risk aversion) and reduces uncertainty, though to a lesser extent. Bruno and Shin (2015) complemented Bekaert *et al.*'s (2013) analysis by showing that an expansionary shock to US monetary policy leads to a reduction in the VIX index, an increase in the leverage of international banks and, finally, in cross-border (banking) capital flows.

In what follows, we put forward that a similar mechanisms may be at play for EU-6 economies: the ultra-low interest rate environment generated by the highly accommodative monetary stance implemented by the ECB should have had a favourable bearing (i.e. a downsizing impact) not only on a region-wide measure of investors' attitude towards risk (i.e. the VSTOXX index), but also on volatility developments in individual EU-6 financial markets. The underlying mechanism would be represented again by the different set of effects making up the "risk-taking" channel of monetary policy.

Against this background, to our best knowledge the objective of empirically identifying the impact of AEs unconventional monetary policies onto the *volatility* of financial variables in EMEs has received very little attention in the existing literature. Converse (2015) was the first to assess the extent to which the quantitative easing programmes implemented by the Federal Reserve affected the volatility of stock and long-term government bond markets in a panel of 18 EMEs. After computing country- and financial market-specific conditional volatilities,[9] he used fixed-effect panel regressions to assess which domestic and global variables impacted on such volatilities over the 2-year period centred on the date of the Federal Reserve's announcement of the quantitative easing 3 (QE3) programme in late 2012. His results show that the average level of bond yield volatility in the QE3 period remains significantly *higher* than in the years prior to the launch of such a programme, while conditional volatility in equity returns is not significantly different across the two periods. By means of a two-step approach, Apostolou and Beirne (2017) estimated the extent to which volatility in real and financial variables in a sample of EMEs can be explained by the volatility of the ECB's and the Federal Reserve's balance sheets over the period 2003-2014.[10] Overall, while only a very limited effect was found on the volatility of real economy variables, EMEs financial markets seem to be particularly susceptible to volatility spillovers from both the Central banks' actions. In particular, their findings suggest that while changes in their balance sheets is accompanied by a dampening impact on stock market volatility, the opposite holds true for the foreign exchange and the bond markets. In general, moreover, while spillovers from the Federal Reserve can explain some of the volatility in almost all EMEs' financial markets, those generated by the ECB's actions appear to be more limited in terms of affected countries, which are nevertheless concentrated among those belonging to Central and Eastern Europe. Finally, they also showed that volatility spillovers from the actions of both the Federal Reserve and the ECB have a time-varying nature and were exacerbated at the height of the global financial crisis, while being reduced afterwards.

In this work, we improve upon the existing literature along several dimensions. First of all, we provide new insights to the nascent debate about the spillovers triggered by unconventional monetary measures implemented by AEs central banks onto volatility developments in EMEs financial markets which, to the best of our knowledge, has appeared only in a limited number of studies up to date. Second, we use an econometric technique (the DCC-MGARCH) which, while remaining in the mainstream of the GARCH models, can adequately take on board not only several variables in the specification of the conditional variance for the different financial markets, but also volatility clustering and important cross-market correlations. At the same time, it allows for a sufficient degree of flexibility in the estimation procedure and a relatively light computational burden. Third, we analyse volatility spillovers by resorting to a wide set of proxies which are adequately "treated" to describe, as far as possible, the actual impact of the ECB's non-standard monetary policies. The

[9] Calculated as the fitted values of an ARCH(2) model.

[10] First, they estimate a GARCH(1,1) on changes in the ECB's and the Federal Reserve's balance sheets, calculating the innovation between the actual change in each central bank's balance sheet and the corresponding fitted values. Then, they add such an innovation to a second GARCH(1,1), this time estimated on both financial (exchange rates, stock exchange return and bond spreads) and real (inflation and industrial production) variables.

approach suggested by Apostolou and Beirne (2017), in fact, raises some relevant questions about the reasons underlying the changes in ECB's balance sheet – which may depend on factors not necessarily connected to the implementation of non-standard policies – and the relatively low frequency of the financial data series – which could be strongly affected by missing macroeconomic fundamentals, therefore hinting to an issue of a (potentially relevant) omitted variable bias. Fourth, the estimation exercise is also performed on a rather long time span, ranging from January 2007 to December 2016, which enables us not only to obtain more reliable and accurate estimates of the different linkages underlying the chosen variables, but also to study the whole period throughout which the ECB implemented different waves of APPs comprising the "expanded" one enacted by end-2014. Finally, we focus on financial markets only – which are supposed to bear the brunt of volatility changes – and on a narrow set of countries – the EU-6 economies, in light of their strong financial linkages with the euro area – which we retain would help us to better figure out the existence, and the extent, of the volatility spillovers stemming from the implementation of the ECB's non-standard monetary policies.

4. The DCC-MGARCH model

In this section, we provide an answer to our research question – i.e. whether, and to what extent, the implementation of asset purchase programmes by the ECB might have contributed to containing asset price volatility in EU-6 economies' financial markets – by means of a battery of country-specific DCC-MGARCH models, estimated on stock and exchange rate returns and on changes in long-term bond yields along the lines of Ananchotikul and Zhang (2014).[11] In this regards, **Appendix I** contains a thorough analysis of the statistical properties of the financial series in question, suggesting that the best specification appears to be an AR(1)-GARCH(1,1) one.

The advantage of using a DCC-MGARCH framework over other similar techniques is two-fold: on the one hand, it is known that asset returns exhibit significant volatility clustering, i.e. high volatility tends to be followed by high volatility, making it important to allow for time-dependent volatility to correctly capture the dynamics of asset prices;[12] on the other hand, the DCC-MGARCH model is able to take on board interconnections between the volatility processes of the three assets in question, which permits to seize important cross-market spillover effects. In particular, the DCC-MGARCH model lets these spillovers change over time, which is often the case with financial variables.[13]

[11] The authors analyse whether volatility developments in a panel of 17 EMEs equity, long-term government debt and foreign exchange (*vis-à-vis* the USD) markets depend on portfolio capital inflows and global risk aversion and whether this relationship changed when the global financial crisis erupted. After having identified likely determinants of portfolio inflows by running country-by-country and market-by-market VAR regressions, they turned to implement DCC-MGARCH models to assess the relative role played by portfolio inflows and global volatility developments in affecting asset returns and volatility dynamics in EMEs financial markets, with a view also to detecting likely cross-market volatility correlations. Their results show that portfolio flows had a substantial effect on asset returns, which was further amplified during the global financial crisis; on top of this, shocks to global risk aversion proxied by the VIX index were found to have a significant impact on country- and market-specific volatility developments, with the magnitude of this effect varying with the macroeconomic and structural characteristics of the individual EMEs covered in the analysis.

[12] See, for example, Poon and Granger (2003) for a survey of the literature on this point.

[13] The DCC-MGARCH model was first proposed by Engle (2002) and since then has been widely used and extended to study dynamic co-variances and correlations across financial asset prices. Cappiello *et al.* (2006) extended the model to allow for asymmetries in correlation dynamics in the behaviour of international equities and bonds.

4.1 Technical background

The MGARCH family comprises dynamic multivariate regression models in which the conditional variances and co-variances of the errors follow an autoregressive-moving-average (ARMA) structure. MGARCH models are aimed to explain how the co-variances among asset classes move over time. Against this background, two critical issues arise: first, when moving from a single univariate GARCH model to MGARCH models – the latter meant to be a "straightforward extension" of the univariate model (Bauwens *et al.,* 2006) – the number of parameters to be estimated increases very rapidly. On top of the high-dimensionality problem, which weighs on parameter estimates, the co-variance matrix must be positive definite (Pourahmadi, 1999). Hence, the crucial stage in MGARCH modelling is to provide a realistic but parsimonious specification of the co-variance matrix ensuring its positivity, while trying to minimize the number of parameters to be estimated.

The general MGARCH model is composed of a *mean* equation and a *volatility* equation, according to equations (1) and (2), respectively:

$$y_t = C\, x_t + \epsilon_t \quad (1)$$

$$\epsilon_t = H_t^{1/2} v_t \quad (2)$$

where y_t is an *mx1* vector of dependent variables, C is an *mxk* matrix of parameters, x_t is a *kx1* vector of independent variables, $H_t^{1/2}$ is the Cholesky factor of the time-varying conditional covariance matrix H_t and v_t is an *mx1* vector of zero-mean, unit-variance i.i.d. innovations.

Within the MGARCH family, there are many different classes of models, which differ in the parsimony and flexibility of their specifications for the time-varying conditional covariance matrix of the disturbances H_t. The Diagonal Vech class pioneered by Bollerslev, Engle, and Wooldridge (1988), for instance, parameterises each element of H_t as a linear function of its own past and past shocks, whereas the Conditional Correlation (CC) class models the diagonal elements of H_t as univariate GARCH processes and the off-diagonal elements as non-linear functions of the diagonal terms. More precisely, in conditional correlation models H_t is traditionally decomposed into a matrix of conditional correlations R_t and a diagonal matrix of conditional variances D_t, as in equation (3):

$$H_t = D_t^{1/2} R_t D_t^{1/2} \quad (3)$$

Within this last class, the Constant Conditional Correlation (CCC) models treat the cross-equation parameters that weigh the non-linear combinations of the conditional variances as constant, while both the Varying Conditional Correlation (VCC) models and the Dynamic Conditional Correlation models (DCC) allow these weights to be time-varying and to follow the GARCH-like processes specified in Tse and Tsui (2002) and Engle (2002), respectively.

In the specification of the *volatility* equation provided by DCC-MGARCH models, the matrix D_t includes the conditional variance of each of the asset returns as in (4)

$$D_t = \begin{pmatrix} \sigma_{S,t}^2 & 0 & 0 \\ 0 & \sigma_{B,t}^2 & 0 \\ 0 & 0 & \sigma_{E,t}^2 \end{pmatrix} \quad (4)$$

where each $\sigma_{i,t}^2$ (where *i* stands for *S, B* or *E*) is assumed to follow a GARCH(1,1) process which, on its turn, is specified as follows:

$$\sigma_{i,t}^2 = c_{\sigma,i} + \delta_i \sigma_{i,t-1}^2 + \zeta_i \varepsilon_{i,t-1}^2 + exp\left(\theta_i z_{i,t}\right) \quad (5)$$

where δ_i and ζ_i represent, respectively, the ARCH and GARCH parameters and the vector of coefficients $\theta_i = (\theta_1, \theta_2)$ measures the impact of additional possible regressors.[14] At the same time, the matrix R_t in equation (3) includes the conditional correlations $\rho_{ij,t}$ among the prices of the financial instruments i and j, which are allowed to be time-varying:

$$R_t = \begin{pmatrix} 1 & \rho_{sb,t} & \rho_{se,t} \\ \rho_{sb,t} & 1 & \rho_{be,t} \\ \rho_{se,t} & \rho_{be,t} & 1 \end{pmatrix} \quad (6)$$

$$R_t = diag(Q_t)^{-1/2} Q_t diag(Q_t)^{-1/2} \quad (7)$$

$$Q_t = (1 - \lambda_1 - \lambda_2)R + \lambda_1 \tilde{\varepsilon}_{t-1} \tilde{\varepsilon}'_{t-1} + \lambda_2 Q_{t-1} \quad (8)$$

In the previous formulas, $\tilde{\varepsilon}_t = {D_t}^{-1/2}$ is a *mx1* vector of standardized residuals while λ_1 and λ_2 are the parameters driving the dynamics of conditional correlations, being both non-negative and satisfying the condition $\lambda_1 + \lambda_2 < 1$. Finally, the R_t matrix is a weighted average of the unconditional covariance matrix of the standardized residuals $\tilde{\varepsilon}_t$.

The DCC-MGARCH models have several convenient practical advantages with respect to their family-mates. First, they are flexible enough since they allow the volatility of different assets to follow different univariate GARCH models. Second, the number of parameters grows linearly with the number of assets and therefore the model is relatively parsimonious, implying that this class of models is suitable for estimation involving a large set of assets.[15] Finally, the parameters are estimated in a two-step procedure, such that the overall number to be estimated simultaneously is relatively small: in the first step, univariate GARCH models are estimated for each asset; using the standardized residuals obtained from the first step, the model parameters of the correlation between assets are estimated. This approach reduces the computational time considerably. At the same time, such a two-step procedure could bring about efficiency losses in the estimation procedure (Wong and Vlaar, 2003).[16] In a nutshell, the DCC-MGARCH models are about as flexible as the closely related VCC-MGARCH models, more flexible than the CCC-MGARCH models and more parsimonious than the DVECH-MGARCH models.

4.2 Model specification

In our model, which is estimated on a country-by-country basis, equation (1) is intended to capture the effect that a host of factors is expected to have on the *level* of asset returns in the generic country *i*. More precisely, it is specified as follows:

[14] The last term in equation (6) allows us make the volatility equation depend on other terms than past realization of errors and volatility itself, with the exponential operator assuring that volatility remains positive.

[15] See Bauman *et al.* (2006) for a review of the computational burden associated with the estimates of different classes of MGARCH models.

[16] Using a two-step procedure causes loss of efficiency because the optimal parameters in the first step are not necessarily optimal in the second step of the estimation procedure. Moreover, misspecification of the univariate models in the first step will affect the parameters in the second step: for instance, when the univariate series exhibit asymmetries, ignoring these effects will influence the correlation parameters in the second step.

$$\begin{pmatrix} S_t \\ B_t \\ E_t \end{pmatrix} = \begin{pmatrix} C_s \\ C_b \\ C_e \end{pmatrix} + \begin{pmatrix} \delta_s & 0 & 0 \\ 0 & \delta_b & 0 \\ 0 & 0 & \delta_e \end{pmatrix} \begin{pmatrix} S_{t-1} \\ B_{t-1} \\ E_{t-1} \end{pmatrix} + \begin{pmatrix} \alpha_s & \beta_s & \gamma_s \\ \alpha_b & \beta_b & \gamma_b \\ \alpha_e & \beta_e & \gamma_e \end{pmatrix} \begin{pmatrix} capital\ flows_t \\ VSTOXX_t \\ ECB's\ APPs_t \end{pmatrix} + \begin{pmatrix} \varepsilon_{s,t} \\ \varepsilon_{b,t} \\ \varepsilon_{e,t} \end{pmatrix} \quad (9)$$

where S_t stands for stock market returns, B_t for the changes in 10-year government bond yields and E_t for the variations in the exchange rate *vis-à-vis* the euro in country *i*, where a positive realisation implies an appreciation.[17] In light of the results contained in the Appendix, we also allow for the presence of an autoregressive component in the formulas describing the dynamics of the three series of asset price changes.[18]

At the same time, in the GARCH (1,1) processes governing the behaviour of the conditional co-variances as per equation (4) the set of potential additional regressors is initially set as $z'_{i,t}$ = ($VSTOXX_t$; *ECB's* $APPs_t$)' to measure the impact of such external factors on volatility developments in EU-6 countries' financial markets.

As per the previous specifications, the *mean* and the *volatility* equations are supposed to be governed by the evolution of a number of regressors in addition to the respective AR(1) and GARCH(1,1) components. In particular: i) *capital* $flows_t$ refers to the net portfolio inflows to EU-6 economies for registered funds from Emerging Portfolio Fund Research (EPFR),[19] which are calculated as *z-scores* of equity flows, bond flows and total portfolio flows used, respectively, in the *mean* equations of the stock market returns, bond yield changes and foreign exchange variations;[20] ii) $VSTOXX_t$ is the EURO STOXX 50 volatility index and is intended to capture the impact of external shocks on international investors' degree of risk aversion; iii) *ECB's* $APPs_t$ includes different proxies to describe the functioning, and measure the impact, of the programmes of asset purchases the ECB has been implementing since July 2009. Three different indicators are taken into account: i) the weekly average of 10-year yields on euro area AAA-rated government bonds (Korniyenko and Loukoianova, 2015; Ciarlone and Colabella, 2016); ii) the weekly average of the shadow rate developed by Wu and Xia (2016) for the euro area (IMF, 2016); iii) a quantity, rather than a price, indicator represented by the increase in the ECB's holdings of securities for monetary purposes (IMF, 2016; Ciarlone and Colabella, 2016). **Chart 2** contains the time evolution of these three proxies, which appear to be clearly related to one another.

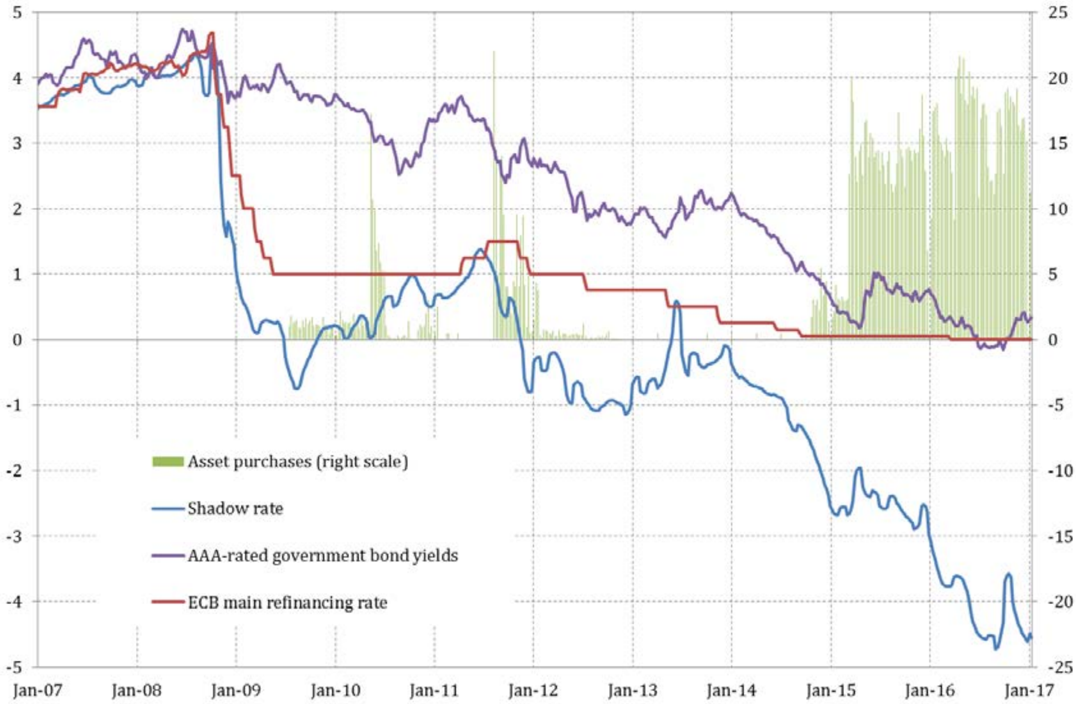
[17] The choice of using changes in interest rate yields in 10-year government bond rather of employing yields in levels was made to align our work with the existing literature on the topic.

[18] We set to zero the cross-term in the second term of the mean equation for a number of reasons. To begin with, we initially checked for the existence of cross-correlation between the different variables at stake finding it only in a rather limited number of cases. This notwithstanding, we tried to include such terms in a new set of regressions: however, such cross-terms turned out often being insignificant. Second, there were also instances where models estimated with the cross-market terms were not able to converge, therefore giving us a further reason to prefer relying on simpler specifications homogeneous across markets and countries.

[19] EPFR collects and aggregates data on the investment activity of a large number of individual funds specialized in asset allocation towards the countries belonging to our sample (among others). In particular, we focus our attention on the share of individual funds originating in the European Union because they are more likely to be affected by the ECB's decisions.

[20] This is essentially done to assure cross-country comparability of the net portfolio inflow series. As it is standard, the *z-scores* are calculated by subtracting the mean from the weekly flows, then dividing by the standard deviation.

Chart 2. Proxies of the ECB's APPs
(weekly data; billions of euros and percentages)



Source: Datastream, European Central Bank, Prof. Cynthia Wu's website.

Beyond depending on their own lagged values, the *level* of financial asset returns in the *mean* equation is supposed to show a direct relationship with the size of the portfolio inflows destined to any given EU-6 country: higher inflows would be typically associated with an increase in stock market indices (+), a compression of government bond yields (–) and an appreciation of local currencies *vis-à-vis* the euro (+). At the same time, external shocks to global volatility – traced by the VSTOXX index – are thought to be inversely related to the level of financial asset returns, since they would generate a plunge in stock prices (–), an increase in long-term yields (+) and downward pressures on the exchange rate (–). Finally, asset returns in EU-6 financial markets are expected to show a direct relationship with the implementation of asset purchase programmes by the ECB. In fact, under the hypothesis that a portfolio rebalancing channel of transmission of such non-standard monetary measures is actually at play,[21] the increase in the ECB's holdings of securities, along with the related

[21] The portfolio rebalancing channel is based on the mechanism whereby outright purchases of public and private securities modify the size and the composition of the balance sheet of both the central bank and the private sector, affecting the economy in this way. As these measures involve the acquisition of longer-duration assets and a rise in bank reserves, they increase the liquidity holdings of the sellers, inducing a rebalancing of investors' portfolios towards the preferred risk-return configuration. A necessary condition for this channel to be effective is the imperfect substitutability among different assets, i.e. assets are not perceived as perfect substitutes by investors, due to the presence of economic frictions. By purchasing a particular security, the central bank reduces the amount of that security held by private agents, usually in exchange for risk-free reserves. As a result, asset prices increase and long-term interest rates fall, creating more favourable conditions for economic recovery.

compression of euro area AAA-rated government bond yields or the shadow rate, would typically generate a positive push on financial market valuations in EU-6 countries.[22]

In turn, the *volatility* of financial asset returns is supposed to show a direct relationship (+) with the VSTOXX index, reflecting the natural transmission of shocks from global to local markets. As regards the expected association with the ECB's APPs, the hypothesis we would like to test here is the existence of a mitigating impact on volatility developments in EU-6 countries' financial markets stemming from the implementation of such non-standard measures, reflecting the functioning of the "risk taking" channel of transmission as well as the working of the "funding (cash)" and "market" liquidity mechanisms. Given that we are using three different proxies, this hypothesis would translate into different expected signs for each of these measures: on the one hand, we would expect to see an inverse (i.e. negative) relationship with the flow of financial assets actually purchased by the ECB (i.e. the larger the flows, the lower the volatility); on the other hand, we would expect a direct (i.e. positive) relationship with the average level of 10-year yields on euro area AAA-rated government bonds and the shadow rate (i.e. the lower the rates, the lower the volatility).

The model is estimated on a country-by-country basis by maximum likelihood using weekly data covering the period from January 2007 to December 2016.

The use of the three proxies intended to describe the functioning, and measure the impact, of ECB's non-standard monetary measures may raise some interpretation issues. The first one relates to the meaning to give to the estimated coefficients, i.e. do they truly represent causal relationships or are they just correlations? EU-6 countries can be fairly classified as small open economies which take external conditions as given; against this background, since each of the three proxies can be considered to be exogenous for the developments in EU-6 financial markets, we retain this solves the problem in favour of a causality relationship.[23]

Another problem relates to the identification of the impulse driven by the three proxies. To begin with, one may argue that volatility developments in EU-6 economies may depend on some euro area macroeconomic factor related to the implementation of the APP but not directly taken into account in the estimation procedure. We think this problem is greatly downsized once the use of weekly data is properly taken into account, since such high frequency data reflect more of the available information for estimation purposes than macroeconomic variables. Second, two of our proxies are, by nature, continuous variables and available for the whole time span under study; therefore, one may argue that their behaviour may depend on factors quite apart from the actual implementation of outright financial asset purchases implemented by the ECB – ranging from standard as well as other non-standard monetary policy measures to innovations that may be independent of any monetary policy action (Peersman, 2011) – and that what the estimation results are capturing is not necessarily the

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[22] There is an ample literature on the impact that the different waves of quantitative easing programmes implemented by the Federal Reserve had on EMEs asset prices and financial conditions more broadly. The main conclusions may be summarised as follows: such unconventional monetary policies brought about significant capital flows toward EMEs, generating a complementary surge in liquidity and asset price bubbles, leading some policy makers from these economies to dub such phenomenon as a 'monetary tsunami' or even 'currency wars'.

[23] IMF (2016) follows a similar approach: in the analysis of the external impact of ECB's non-standard measures, it employs, among other procedures, country-by-country VARs where the same set of proxies are directly considered in the exogenous block.

actual impact of the ECB's APPs.[24] The identification of non-standard monetary policy shocks is still an uncharted territory and represents a key challenge for econometricians, not least as these measures are somewhat unprecedented in modern central banking history and the instruments vary widely across the various non-standard measures (Darracq-Paries and De Santis, 2013). Though an extensive theoretical literature has discussed the various policy alternatives when the policy rate hits the zero lower bound, the empirical literature is only gradually emerging as data are collected and solutions to identification issues are found.

To address this concern, and to keep our proxies as close as possible to the time evolution of outright asset purchases, we introduce two refinements.

As regards the level of 10-year yields on euro area AAA-rated government bonds, we use the two-step procedure originally proposed by Ahmed and Zlate (2014) – and subsequently employed by Korniyenko and Loukoianova (2015) and Ciarlone and Colabella (2016) – which is aimed to isolate the changes in such yields that can be considered as directly attributable to the implementation of the ECB's non-standard monetary measures. In the first stage, a simple OLS regression over the period from July 2009 to December 2016 is run, where the ECB's one-week ahead actual gross asset purchases are used as an explicit determinant of the weekly average of euro area AAA-rated government long-term yields; estimation results show the existence of a significant relationship between the two variables, with the actual realization of these non-standard programmes having been accompanied by a reduction in long-term interest rates.[25] In the second stage, the fitted values of this regression (less the respective estimated constants) are used in the *volatility* equation as a proxy of the effects of the ECB's APPs, with the expected sign being positive to indicate a direct relationship with the volatility measures (i.e. a reduction in euro area AAA-rated government long-term yields determined by the actual implementation of asset purchases is associated with a lower volatility in EU-6 countries financial markets).

As regards the shadow rate, we look at whether the launch of the different waves of APPs may have altered the impact of this continuous proxy on volatility developments in EU-6 financial markets. In particular, we augment the basic representation of the *volatility* equation with an additive and an interaction dummy, with the vector of external regressors now looking as $z_{i,t}$ = ($VSTOXX_t$; $ECB's\ APPs_t$; $Dummy_\tau$; $Dummy_\tau$ x $ECB's\ APPs_t$) with an accordingly updated vector of coefficients $\theta_i = (\theta_1; \theta_2; \theta_3; \theta_4)$. The additive term $Dummy_\tau$ is set equal to 0 until a given date and 1 afterwards, and is intended to modify the *average* level of volatility in EU-6 financial markets after the 'treatment' represented by the launch of different waves of APPs. The interaction term $Dummy_\tau$ x $ECB's\ APPs_t$, in turn, is intended to assess the existence of a differential – by sign, magnitude and significance level – impact on volatility developments in EU-6 financial markets, respectively, before and after the chosen cut-off date. More precisely, while θ_2 would measure the impact of the chosen proxy on $\sigma^2_{i,t}$ before the occurrence of the event (i.e. when $Dummy_\tau$ is set to 0), ($\theta_2 + \theta_4$) would measure it after the occurrence of the event (i.e. when $Dummy_\tau$ is shifted to 1). As regards the choice of the cut-off date, we decided to experiment with the week ending the 9th of December 2011, for a number of reasons: as the euro area sovereign debt

[24] As a matter of fact, in the period under study the euro area's main refinancing rate was slashed from a level as high as a 4.25% in the second half of 2008 to a low of 0.00% in place since March 2016. Moreover, since July 2013 the ECB has introduced, and actively used, 'forward guidance' – a policy consisting of providing explicit statements on the conditional orientation of monetary policy with respect to the future path of policy interest rates – which, especially in periods of heightened financial volatility, has served as an effective tool to steer market expectations of future short-term interest rates more tightly around the desired monetary policy stance of the ECB.

[25] The estimated equation is $AAA\text{-}rated\ yields_t = 2.476211 - 0.1160 * ECB's\ APPs_{t+1}$, with the coefficient of asset purchases being significant at the 1% level.

crisis reached its peak, the ECB stepped in by reactivating, in August 2011, the Securities Market Programme, with interventions much larger than before (i.e. the ECB almost tripled its stock of holdings from 70 to more than 200 billion euros at market prices); moreover, on the 8th of December 2011 the Governing Council decided to conduct two longer-term refinancing operations (LTROs) with a maturity of 36 months which, though not representing a true asset purchase programme, undoubtedly sent an important signal to reassure market participants about the willingness to support bank lending and money market activity in the euro area. As a consequence, Chart 2 clearly indicates that starting from this date the shadow rate entered into negative territory, where it has remained almost continuously until the present. Essentially for this reason, we consider this date as a useful benchmark to assess the differential impact of our continuous proxy on volatility developments in EU-6 financial markets.[26]

To help the reader to interpret the estimation results, **Table 1** offers an overview of the expected signs of the coefficients of our set of variables for both the *mean* and the *volatility* equations for each of the three markets considered here.

Table 1. Expected signs for the host of regressors

	Stock		Bond		Foreign exchange	
	Mean eq.	Volatility eq.	Mean eq.	Volatility eq.	Mean eq.	Volatility eq.
Portfolio inflows	+		–		+	
VSTOXX index	–	+	+	+	–	+
ECB's asset purchases	+	–	–	–	+	–
AAA-rated bond yields	–	+	+	+	–	+
Shadow rate	–	+	+	+	–	+
APPs impact on AAA-rated bond yields	–	+	+	+	–	+

4.3 Estimation results

We begin by showing, in **Table 2**, the estimation results for the battery of country-specific DCC-MGARCH models, where initially there is no role for our chosen set of proxies measuring the working and the impact of the ECB's non-standard monetary measures.[27]

As regards the *mean* equation, the presence of a widespread strong autocorrelation in asset returns across countries and financial markets is clearly confirmed. Moreover, the *level* of financial asset returns is affected by portfolio inflows, an effect that is both statistically and economically significant. This turns out to be particularly true in the case of stock markets, where a one standard

[26] We are taking here an approach quite similar in spirit to the one used by the Federal Reserve as regards the shadow rate calculated for the US: as reported in the website of the Atlanta Fed (the interested reader may consult the webpage, it appears that the shadow rate series has been calibrated to be equal to the federal funds target rate when such a rate is above or equal to 25bp; in other words, a shadow rate would exist only when the federal funds' target rate has reached the ZLB. Of course, in the case of the shadow rate calculated for the euro area it is clear that on the 9th of December 2011 the reference marginal rate was still well above the ZLB. We think, nevertheless, that this cut-off date undoubtedly represents a sort of watershed in light of what was happening in the euro area, the risks it was facing and the response given by the ECB in terms of newly adopted non-standard monetary measures.

[27] Throughout the paper, we use the following simple rule for formatting the tables reporting the estimation results: a bold font is used to signal a coefficient that comes out with the expected sign, while a shaded area is used to signal the occurrence of a coefficient that turns out as both having the correct expected sign and being statistically significant at conventional levels.

deviation increase in portfolio inflows is able to generate a 25.0% increase in returns on average among the EU-6 economies.[28] As regards the bond and the foreign exchange markets, coefficients related to portfolio inflows often have the expected sign, but are less statistically significant: on average, a one standard deviation increase in bond (total) portfolio inflows coincides with a decrease (an appreciation) in yields (in foreign exchanges) by 119bp (1.3%) on average across the six countries. Finally, in the *mean* equation the level of asset returns turns out to be significantly affected by increases in international investors' degree of risk aversion: as expected, a rise in the VSTOXX index is typically associated with a fall in stock market indices, an increase in sovereign bond yields and a depreciation of domestic currencies *vis-à-vis* the euro.

Likewise, changes in global risk aversion have significant effects on the *volatility* of asset returns across EU-6 economies. An increase in the VSTOXX index, in fact, triggers a significant surge in volatility in all three financial markets with the impact being more pronounced for the stock and foreign exchange markets, where a one unit increase in the index generates an increase in asset return variances by 2.9% in the former and 3.7% in the latter market, respectively. By contrast, our chosen measure of international investors' degree of risk aversion seems to have a much more limited effect on volatility in EU-6 bond markets: although it always shows up with the expected sign, the VSTOXX index comes out as statistically significant only in three out of the six countries in the sample; for those three, on average, a one unit increase in the index generates an increase in bond market volatility by almost 2.0%.

Financial asset prices tend to exhibit strong co-movements across the three markets. More precisely, the estimated correlations show that exchange rate changes are generally more closely related to stock market returns than either series to changes in bond yields. This might reflect the fact that equity flows convey more private information about the state of the economy than bond flows do. Thus, equity flows might have a greater price impact on the domestic currency, leading to a closer linkage between stock prices and the exchange rate than between bond yields and the exchange rates.

[28] As we use *z-scores* for portfolio flows, a given increase in this variable corresponds to an increase in its standard deviation. Admittedly, though coherent with those reported in Ananchotikul and Zhang (2014), these results may still seem implausibly large; this may be because the size of one standard deviation of the weekly equity flows to EU-6 economies is relatively small.

Table 2. DCC-MGARCH estimates: initial specification

	Bulgaria	Croatia	Czech Rep.	Hungary	Poland	Romania
Stock markets						
Mean equation						
Constant	3.970	2.773	5.266	2.892	4.939	5.307
	(0.851)***	(0.879)***	(1.566)***	(1.394)**	(1.254)***	(1.625)***
L.stock market returns	**0.300**	**0.318**	**0.153**	**0.153**	**0.179**	**0.155**
	(0.050)* **	**(0.056)*** **	**(0.054)*** **	**(0.049)*** **	**(0.045)*** **	**(0.053)*** **
VSTOXX	**-0.014**	**-0.009**	**-0.017**	**-0.009**	**-0.016**	**-0.017**
	(0.003)* **	**(0.003)*** **	**(0.005)*** **	**(0.005)** **	**(0.004)*** **	**(0.005)*** **
Portfolio flows	**0.224**	**0.149**	**0.214**	**0.281**	**0.201**	**0.397**
	(0.084)* **	**(0.105)* **	**(0.106)** **	**(0.076)*** **	**(0.122)* **	**(0.102)*** **
Volatility equation						
Constant	-6.819	-15.626	-8.005	-6.440	-7.324	-8.342
	(1.447)***	(4.292)***	(1.003)***	(1.010)***	(1.714)***	(1.393)***
L.ARCH	0.278	0.221	0.229	0.031	0.142	0.233
	(0.069)***	(0.091)**	(0.089)***	(0.078)	(0.042)***	(0.076)***
L.GARCH	0.500	0.721	0.152	0.300	0.773	0.332
	(0.125)***	(0.108)***	(0.161)	(0.188)*	(0.069)***	(0.357)
VSTOXX	**0.023**	**0.043**	**0.028**	**0.024**	**0.020**	**0.029**
	(0.005)* **	**(0.012)*** **	**(0.003)*** **	**(0.002)*** **	**(0.006)*** **	**(0.003)*** **
Bond markets						
Mean equation						
Constant	-2.868	-0.306	-1.688	-7.126	0.087	-2.651
	(5.801)	(0.051)***	(3.742)	(10.055)	(5.200)	(5.360)
L.bond yield changes	**0.123**	**0.211**	**0.457**	**0.217**	**0.192**	**0.044**
	(0.061) **	**(0.081)*** **	**(0.044)*** **	**(0.053)*** **	**(0.044)*** **	**(0.066)**
VSTOXX	**0.006**	**0.001**	**0.004**	**0.020**	-0.001	**0.009**
	(0.018)	**(0.000)*** **	**(0.012)**	**(0.033)**	(0.016)	**(0.018)**
Portfolio flows	**-0.350**	**-0.012**	0.054	**-1.478**	**-1.271**	**-1.902**
	(0.619)	**(0.003)*** **	(0.308)	**(0.932)* **	**(0.588)** **	**(0.611)*** **
Volatility equation						
Constant	-2.695	-1.363	-3.996	-3.621	1.569	-6.159
	(2.639)	(3.483)	(2.140)**	(1.517)**	(3.047)	(12.218)
L.ARCH	0.260	1.180	0.201	0.264	0.131	0.439
	(0.144)*	(0.417)***	(0.089)**	(0.119)**	(0.039)***	(0.200)**
L.GARCH	0.622	0.364	0.475	0.305	0.803	0.652
	(0.109)***	(0.125)***	(0.343)	(0.234)	(0.047)***	(0.158)***
VSTOXX	**0.018**	-0.244	**0.022**	**0.027**	**0.001**	**0.026**
	(0.009) **	(0.055)***	**(0.005)*** **	**(0.004)*** **	**(0.010)**	**(0.035)**
FX markets						
Mean equation						
Constant		-0.063	0.186	0.609	1.141	0.430
		(0.099)	(0.120)	(0.415)	(0.493)**	(0.237)*
L.FX returns		**0.290**	**0.149**	**0.149**	**0.167**	**0.137**
		(0.056)* **	**(0.062)** **	**(0.046)*** **	**(0.039)*** **	**(0.059)** **
VSTOXX		0.000	**-0.001**	**-0.002**	**-0.004**	**-0.001**
		(0.000)	**(0.000)**	**(0.001)* **	**(0.002)** **	**(0.001)** **
Portfolio flows		**0.016**	-0.001	**0.013**	**0.019**	**0.022**
		(0.007) **	(0.009)	**(0.038)**	**(0.029)**	**(0.013)* **
Volatility equation						
Constant		-12.397	-41.155	-8.453	-11.133	-6.453
		(1.720)***	(4.901)***	(1.00)***	(0.864)***	(3.755)*
L.ARCH		0.224	0.272	0.095	0.010	0.250
		(0.051)***	(0.125)**	(0.043)**	(0.032)	(0.082)***
L.GARCH		0.702	0.783	0.417	0.788	0.712
		(0.036)***	(0.075)***	(0.198)**	(0.077)***	(0.082)***
VSTOXX		**0.021**	**0.098**	**0.020**	**0.029**	**0.008**
		(0.005)* **	**(0.013)*** **	**(0.002)*** **	**(0.002)*** **	**(0.012)**
corr(Stock - Bond markets)	-0.050	-0.056	-0.031	-0.376	-0.273	-0.245
	(0.045)	(0.051)	(0.065)	(0.051)***	(0.066)***	(0.148)***
corr(Stock - FX markets)		0.076	0.197	0.470	0.506	0.337
		(0.054)	(0.063)***	(0.048)***	(0.062)***	(0.154)***
corr(Bond - FX markets)		-0.024	-0.050	-0.554	-0.387	-0.314
		(0.047)	(0.066)	(0.039)***	(0.066)***	(0.139)***
Observations	523	466	523	523	523	523

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

To this basic representation we add separately each of the three proxies chosen to represent the working and the impact of the ECB's non-standard monetary measures. **Tables 3.a**, **3.b** and **3.c** show the estimation outcomes relative to the increase in the ECB's holdings of securities for monetary purposes, the weekly average of 10-year yields on euro area AAA-rated government bonds and the weekly average of the euro area shadow rate, respectively. Some key conclusions can be drawn. First of all, their role in affecting the *level* of asset returns seems to be quite limited: the coefficients of the flows of asset purchases, the level of the euro area AAA-rated 10-year government bond yields and that of the Wu and Xia's shadow rate not only come out often with ambiguous signs, but they are also seldom statistically significant. The only exception seems to be the role of the shadow rate in influencing the level of stock market returns: as shown in **Table 3.c**, the estimated coefficients hint to the existence of the expected inverse relationship in the majority of the countries in the sample, which is statistically significant in half of them.[29] By contrast, our three proxies appear to have a clear effect on the *volatility* of asset returns in EU-6 financial markets: the signs of the estimated coefficients often come out as expected, and these coefficients are statistically significant for the majority of EU-6 countries across the different financial markets and model specifications. Hence, this battery of estimation results seems to give a first support to our research question related to the existence of a favourable influence played by the implementation of the APPs in containing volatility in EU-6 financial markets: the flows of financial asset purchases, along with the resulting dynamics of the euro area AAA-rated 10-year government bond yields or the shadow rate, seem to have been able to counter adverse developments in global volatility indicators, thereby shielding EU-6 financial markets from negative external shocks to international investors' risk aversion. In our view, the economic and statistical significance of the estimated coefficients would support the existence of both a "risk-taking" and a "liquidity" channel of transmission stemming from the ECB's non-standard monetary measures, which may operate both directly (on the volatilities of EU-6 financial markets) as well as indirectly (via their impact on the VSTOXX index). These conclusions apply strongly for the stock and the foreign exchange markets;[30] on the contrary, volatility developments in bond markets seem to remain largely unaffected by our three proxies of the ECB's non-standard monetary measures. In fact, with the exception of the flow of asset purchases – for which there appears to be a sufficiently robust evidence of a dampening impact on bond market volatility – [31] both the level of the euro area AAA-rated 10-year government bond yields and the shadow rate do not seem to play an economically and statistically relevant role in affecting volatility developments in EU-6 bond markets, at least when estimations are run throughout the whole available time span and/or without any transformation of those independent variables.[32] On top of this, it has to be borne in mind that the use of proxy variables in the exercise to describe the pattern of the ECB's APPs brings about an attenuation bias in the relative coefficient estimates. Hence, the actual effect of the ECB's APPs on the dependent variables is likely to be stronger than that measured by such coefficient.

[29] The conclusion about the apparent inability of our proxies to affect the level of asset returns should not appear so odd if one simply recollects the existence of a portfolio rebalancing channel of transmission at play: the impact on prices and, therefore, on returns does not operate directly, but rather indirectly, by means of the effect that APPs have of international investors' decisions on how to allocate their asset portfolios.

[30] The euro area AAA-rated 10-year government bond yields and the shadow rate's coefficients in the *volatility* equation turn out with the expected positive sign and they are statistically significant in all the EU-6 countries when considering volatility developments in the stock markets; as regards foreign exchange markets, the sign is again correct in all the six countries under observation, but significant in three of them.

[31] The coefficient comes out being negative as expected in four out of six cases, while being statistically significant in half of the EU-6 economies.

[32] When using the euro area AAA-rated 10-year government bond yields (i.e. the shadow rate), its estimated coefficient turns out with the expected positive sign in three (three) out of six cases, while being statistically significant in just one (i.e. two) occasions.

Table 3.a DCC-MGARCH estimates: role of the flow of asset purchases

	Bulgaria	Croatia	Czech Rep.	Hungary	Poland	Romania
Stock markets						
Mean equation						
Constant	5.609	3.378	5.812	3.890	3.625	4.286
	(1.073)***	(0.965)***	(1.795)***	(1.769)**	(1.427)**	(1.430)***
L.stock market returns	**0.294**	**0.262**	**0.112**	**0.111**	**0.144**	**0.122**
	(0.053)***	**(0.070)*****	**(0.066)***	**(0.058)****	**(0.057)*****	**(0.057)****
VSTOXX	**-0.018**	**-0.011**	**-0.019**	**-0.013**	**-0.011**	**-0.013**
	(0.003)***	**(0.003)*****	**(0.006)*****	**(0.006)****	**(0.005)****	**(0.005)*****
Portfolio flows	-0.090	**0.151**	**0.428**	**0.605**	**0.219**	**0.218**
	(0.209)	**(0.119)**	**(0.218)****	**(0.256)****	**(0.140)***	**(0.078)*****
ECB's asset purchases	**0.008**	**0.013**	-0.007	**0.037**	-0.002	-0.015
	(0.009)	**(0.008)***	(0.012)	**(0.013)*****	(0.012)	(0.011)
Volatility equation						
Constant	-3.080	-8.466	-6.705	-7.242	-5.692	-9.136
	(2.177)	(2.230)***	(1.485)***	(1.461)***	(1.175)***	(1.544)***
L.ARCH	0.244	0.177	0.263	0.114	0.098	0.147
	(0.072)***	(0.098)*	(0.116)**	(0.059)*	(0.062)*	(0.077)*
L.GARCH	0.492	0.654	0.221	0.475	0.147	0.225
	(0.089)***	(0.107)***	(0.200)	(0.195)**	(0.169)	(0.143)*
VSTOXX	**0.010**	**0.026**	**0.023**	**0.025**	**0.021**	**0.032**
	(0.007)	**(0.008)*****	**(0.004)*****	**(0.004)*****	**(0.004)*****	**(0.005)*****
ECB's asset purchases	**-0.058**	**-0.051**	**-0.007**	**-0.032**	**-0.002**	**-0.053**
	(0.028)**	**(0.031)***	**(0.015)**	**(0.016)****	**(0.013)**	**(0.018)*****
Bond markets						
Mean equation						
Constant	3.993	-11.104	-14.036	-3.406	-1.762	-2.127
	(5.116)	(8.941)	(8.319)*	(12.901)	(7.450)	(6.349)
L.bond yield changes	**0.077**	**0.182**	**0.474**	**0.208**	**0.124**	**0.108**
	(0.065)	**(0.081)****	**(0.059)*****	**(0.062)*****	**(0.055)****	**(0.067)***
VSTOXX	-0.019	**0.035**	**0.030**	**0.002**	**0.001**	**0.005**
	(0.017)	**(0.028)**	**(0.019)***	**(0.042)**	**(0.023)**	**(0.020)**
Portfolio flows	**-1.311**	**-0.767**	0.160	**-1.251**	**-1.108**	**-1.795**
	(0.539)**	**(0.298)*****	(0.195)	**(0.902)**	**(0.664)***	**(0.582)*****
ECB's asset purchases	0.100	0.035	0.057	0.236	0.170	0.118
	(0.067)	(0.064)	(0.040)	(0.111)**	(0.070)**	(0.076)
Volatility equation						
Constant	3.282	1.783	-4.497	-0.131	4.504	7.439
	(1.737)*	(4.314)	(4.733)	(1.479)	(2.968)	(19.801)
L.ARCH	0.411	0.608	0.394	0.250	0.067	0.274
	(0.212)**	(0.519)	(0.359)	(0.134)*	(0.035)*	(0.153)*
L.GARCH	0.083	0.405	0.221	0.307	0.857	0.743
	(0.131)	(0.483)	(0.569)	(0.252)	(0.052)***	(0.121)***
VSTOXX	**0.009**	**0.003**	**0.018**	**0.017**	-0.009	-0.020
	(0.005)*	**(0.018)**	**(0.009)****	**(0.004)*****	(0.010)	(0.065)
ECB's asset purchases	**-0.037**	**-0.039**	**-0.062**	**-0.049**	0.033	0.035
	(0.022)*	**(0.044)**	**(0.024)*****	**(0.022)****	(0.024)	(0.060)
FX markets						
Mean equation						
Constant		-0.020	0.128	0.714	0.381	0.773
		(0.097)	(0.096)	(0.671)	(0.573)	(0.320)**
L.FX returns		**0.303**	**0.097**	**0.156**	**0.165**	**0.131**
		(0.060)***	**(0.072)**	**(0.053)*****	**(0.050)*****	**(0.031)*****
VSTOXX		0.000	**0.000**	**-0.003**	**-0.001**	**-0.003**
		(0.000)	**(0.000)**	**(0.002)**	**(0.002)**	**(0.001)****
Portfolio flows		**0.016**	**0.008**	**0.041**	**0.049**	**0.005**
		(0.007)**	**(0.005)***	**(0.045)**	**(0.037)**	**(0.016)**
ECB's asset purchases		**0.000**	-0.001	**0.004**	-0.002	**0.000**
		(0.001)	(0.001)	**(0.005)**	(0.005)	**(0.003)**
Volatility equation						
Constant		-11.056	-19.352	-9.069	-10.142	-4.722
		(1.795)***	(3.555)***	(1.362)***	(1.205)***	(1.576)***
L.ARCH		0.203	0.424	0.015	-0.037	0.237
		(0.058)***	(0.135)***	(0.034)	(0.043)	(0.112)**
L.GARCH		0.710	0.533	0.640	0.457	-0.203
		(0.046)***	(0.080)***	(0.201)***	(0.152)***	(0.079)***
VSTOXX		**0.017**	**0.053**	**0.025**	**0.029**	**0.011**
		(0.006)***	**(0.010)*****	**(0.003)*****	**(0.004)*****	**(0.005)****
ECB's asset purchases		**-0.010**	**-0.317**	**-0.068**	**-0.007**	**-0.061**
		(0.033)	**(0.036)*****	**(0.013)*****	**(0.010)**	**(0.019)*****
corr(Stock - Bond markets)	-0.047	-0.022	-0.019	-0.306	-0.247	-0.103
	(0.055)	(0.056)	(0.076)	(0.109)***	(0.049)***	(0.096)
corr(Stock - FX markets)		0.095	0.222	0.465	0.512	0.162
		(0.056)*	(0.051)***	(0.059)***	(0.043)***	(0.102)*
corr(Bond - FX markets)		0.011	-0.048	-0.515	-0.373	-0.360
		(0.059)	(0.083)	(0.078)***	(0.050)***	(0.153)**
Observations	393	393	393	393	393	393

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 3.b DCC-MGARCH estimates: role of euro area's AAA-rated government bond yields

	Bulgaria	**Croatia**	**Czech Rep.**	**Hungary**	**Poland**	**Romania**
Stock markets						
Mean equation						
Constant	5.428	3.346	5.603	3.023	4.140	4.588
	(1.046)***	(0.830)***	(1.543)***	(1.536)**	(1.182)***	(1.248)***
L.stock market returns	**0.307**	**0.327**	**0.141**	**0.151**	**0.164**	**0.145**
	(0.049)* **	**(0.049)*** **	**(0.056)*** **	**(0.051)*** **	**(0.044)*** **	**(0.048)*** **
VSTOXX	**-0.017**	**-0.011**	**-0.018**	**-0.009**	**-0.013**	**-0.015**
	(0.003)* **	**(0.003)*** **	**(0.005)*** **	**(0.005)* **	**(0.004)*** **	**(0.004)*** **
Portfolio flows	**0.159**	**0.193**	**0.235**	**0.286**	**0.189**	**0.276**
	**(0.099)* **	**(0.084)** **	**(0.105)** **	**(0.080)*** **	**(0.108)* **	**(0.077)*** **
AAA-rated bond yields	**-0.036**	**-0.041**	0.044	**-0.063**	0.028	0.059
	(0.057)	**(0.048)**	(0.052)	**(0.063)**	(0.059)	(0.059)
Volatility equation						
Constant	-4.750	-9.450	-7.785	-6.221	-4.379	-6.941
	(2.520)*	(2.746)***	(0.961)***	(1.220)***	(0.804)***	(0.842)***
L.ARCH	0.279	0.131	0.238	0.045	0.033	0.119
	(0.072)***	(0.050)***	(0.090)**	(0.105)	(0.072)	(0.070)*
L.GARCH	0.503	0.728	0.162	0.316	0.099	0.034
	(0.142)***	(0.111)***	(0.140)	(0.276)	(0.245)	(0.133)
VSTOXX	**0.011**	**0.022**	**0.026**	**0.022**	**0.016**	**0.023**
	(0.008)	**(0.008)*** **	**(0.003)*** **	**(0.003)*** **	**(0.002)*** **	**(0.003)*** **
AAA-rated bond yields	**0.472**	**0.513**	**0.163**	**0.120**	**0.281**	**0.424**
	(0.097)* **	**(0.104)*** **	**(0.064)*** **	**(0.065)* **	**(0.051)*** **	**(0.054)*** **
Bond markets						
Mean equation						
Constant	-2.729	-7.566	-2.622	-6.413	0.624	-2.648
	(5.297)	(6.287)	(3.750)	(10.483)	(5.482)	(6.501)
L.bond yield changes	**0.111**	**0.203**	**0.449**	**0.217**	**0.203**	**0.057**
	**(0.059)* **	**(0.071)*** **	**(0.044)*** **	**(0.053)*** **	**(0.046)*** **	**(0.066)**
VSTOXX	**0.003**	**0.022**	**0.006**	**0.020**	-0.004	**0.005**
	(0.017)	**(0.020)**	**(0.012)**	**(0.033)**	(0.017)	**(0.021)**
Portfolio flows	**-0.456**	**-0.724**	0.107	**-1.543**	**-1.262**	**-1.716**
	(0.487)	**(0.519)**	(0.286)	**(0.962)* **	**(0.636)* **	**(0.555)*** **
AAA-rated bond yields	**0.411**	**0.286**	**0.164**	-0.244	**0.137**	**0.384**
	(0.351)	**(0.210)**	**(0.173)**	(0.411)	**(0.288)**	**(0.451)**
Volatility equation						
Constant	-1.445	-1.468	-3.399	-3.624	0.852	3.963
	(3.118)	(4.105)	(1.724)**	(1.470)***	(0.939)	(8.297)
L.ARCH	0.251	0.582	0.195	0.264	0.192	0.491
	(0.148)*	(0.392)	(0.082)***	(0.117)**	(0.083)***	(0.320)
L.GARCH	0.612	0.432	0.430	0.308	0.225	0.632
	(0.131)***	(0.318)	(0.289)	(0.233)	(0.445)	(0.184)***
VSTOXX	**0.017**	**0.015**	**0.018**	**0.027**	**0.011**	-0.005
	(0.009) **	**(0.010)**	**(0.005)*** **	**(0.004)*** **	**(0.004)*** **	(0.027)
AAA-rated bond yields	**0.114**	-0.219	**0.279**	**0.007**	-0.224	-0.413
	(0.167)	(0.152)	**(0.076)*** **	**(0.083)**	(0.063)***	(0.372)
FX markets						
Mean equation						
Constant		-0.016	0.139	0.719	0.993	0.598
		(0.089)	(0.094)	(0.574)	(0.480)**	(0.249)**
L.FX returns		**0.298**	**0.141**	**0.154**	**0.159**	**0.204**
		(0.051)* **	**(0.059)** **	**(0.046)*** **	**(0.040)*** **	**(0.053)*** **
VSTOXX		**0.000**	**0.000**	**-0.002**	**-0.003**	**-0.002**
		(0.000)	**(0.000)* **	**(0.002)**	**(0.002)** **	**(0.001)*** **
Portfolio flows		**0.016**	**0.005**	**0.015**	**0.029**	**0.009**
		(0.007) **	**(0.006)**	**(0.039)**	**(0.030)**	**(0.015)**
AAA-rated bond yields		0.012	0.029	0.010	0.038	**-0.009**
		(0.005)**	(0.012)**	(0.023)	(0.024)	**(0.016)**
Volatility equation						
Constant		-12.278	-17.050	-7.833	-10.799	-5.256
		(1.787)***	(2.385)***	(0.876)***	(0.843)***	(1.151)***
L.ARCH		0.221	0.411	0.049	0.003	0.307
		(0.055)***	(0.115)***	(0.039)	(0.033)	(0.089)***
L.GARCH		0.707	0.632	0.454	0.760	0.077
		(0.040)***	(0.067)***	(0.190)**	(0.088)***	(0.233)
VSTOXX		**0.021**	**0.028**	**0.020**	**0.027**	**0.007**
		(0.006)* **	**(0.007)*** **	**(0.002)*** **	**(0.002)*** **	**(0.004)** **
AAA-rated bond yields		**0.042**	**1.304**	**0.229**	**0.080**	**0.492**
		(0.145)	**(0.139)*** **	**(0.049)*** **	**(0.048)* **	**(0.078)*** **
corr(Stock - Bond markets)	-0.039	-0.071	0.001	-0.370	-0.244	-0.106
	(0.041)	(0.052)	(0.048)	(0.051)***	(0.058)***	(0.117)
corr(Stock - FX markets)		0.073	0.146	0.462	0.486	0.145
		(0.049)*	(0.046)***	(0.047)***	(0.054)***	(0.110)
corr(Bond - FX markets)		-0.056	-0.053	-0.547	-0.351	-0.433
		(0.045)	(0.053)	(0.042)***	(0.056)***	(0.230)*
Observations	523	466	523	523	523	523

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 3.c DCC-MGARCH estimates: role of the shadow rate

	Bulgaria	Croatia	Czech Rep.	Hungary	Poland	Romania
Stock markets						
Mean equation						
Constant	5.231	3.480	5.475	2.938	3.881	4.065
	(1.029)***	(0.860)***	(1.512)***	(1.562)*	(1.309)***	(1.320)***
L.stock market returns	0.310	0.315	0.148	0.145	0.159	0.158
	(0.049)***	(0.050)***	(0.055)***	(0.049)***	(0.046)***	(0.049)***
VSTOXX	-0.017	-0.011	-0.018	-0.009	-0.012	-0.013
	(0.003)***	(0.003)***	(0.005)***	(0.005)*	(0.004)***	(0.004)***
Portfolio flows	0.146	0.161	0.227	0.273	0.195	0.262
	(0.100)*	(0.086)**	(0.106)**	(0.081)***	(0.107)*	(0.074)***
Shadow rate	-0.046	-0.058	-0.006	-0.067	-0.026	-0.011
	(0.032)*	(0.031)*	(0.030)	(0.034)**	(0.039)	(0.039)
Volatility equation						
Constant	-4.989	-9.912	-7.884	-6.275	-4.794	-6.987
	(1.969)***	(2.088)***	(0.999)***	(1.189)***	(0.911)***	(0.914)***
L.ARCH	0.263	0.096	0.234	0.047	0.033	0.146
	(0.080)***	(0.090)	(0.086)***	(0.099)	(0.080)	(0.065)**
L.GARCH	0.512	0.816	0.208	0.334	0.259	0.129
	(0.144)***	(0.138)***	(0.163)	(0.257)	(0.334)	(0.125)
VSTOXX	0.016	0.026	0.027	0.023	0.018	0.026
	(0.006)***	(0.006)***	(0.003)***	(0.003)***	(0.002)***	(0.003)***
Shadow rate	0.276	0.334	0.089	0.064	0.158	0.242
	(0.057)***	(0.086)***	(0.038)**	(0.037)*	(0.030)***	(0.031)***
Bond markets						
Mean equation						
Constant	-2.896	-8.391	-2.437	-7.998	-0.761	-2.248
	(5.116)	(6.656)	(3.738)	(10.405)	(5.304)	(6.276)
L.bond yield changes	0.113	0.210	0.452	0.217	0.182	0.066
	(0.058)**	(0.071)***	(0.043)***	(0.053)***	(0.045)***	(0.060)
VSTOXX	0.007	0.027	0.007	0.023	0.002	0.007
	(0.016)	(0.021)	(0.012)	(0.034)	(0.017)	(0.020)
Portfolio flows	-0.411	-0.745	0.100	-1.440	-1.227	-1.642
	(0.483)	(0.600)	(0.288)	(0.988)	(0.594)**	(0.568)***
Shadow rate	0.252	0.135	0.149	0.086	0.128	0.261
	(0.192)	(0.121)	(0.098)*	(0.226)	(0.187)	(0.262)
Volatility equation						
Constant	-1.516	-1.973	-3.620	-3.653	2.022	34.947
	(2.996)	(3.419)	(2.296)	(1.461)***	(3.047)	(11.962)***
L.ARCH	0.232	0.535	0.173	0.265	0.129	0.322
	(0.158)	(0.279)**	(0.089)**	(0.117)**	(0.038)***	(0.119)**
L.GARCH	0.630	0.489	0.488	0.292	0.796	0.740
	(0.137)***	(0.185)***	(0.418)	(0.220)	(0.052)***	(0.072)***
VSTOXX	0.018	0.015	0.021	0.027	0.000	-0.116
	(0.008)**	(0.009)*	(0.005)***	(0.004)***	(0.010)	(0.042)**
Shadow rate	0.061	-0.050	0.156	-0.016	-0.034	0.862
	(0.116)	(0.075)	(0.041)***	(0.046)	(0.077)	(0.350)***
FX markets						
Mean equation						
Constant		-0.014	0.211	0.735	0.932	0.415
		(0.090)	(0.113)**	(0.598)	(0.495)*	(0.245)*
L.FX returns		0.299	0.145	0.148	0.164	0.196
		(0.051)***	(0.058)***	(0.046)***	(0.040)***	(0.049)***
VSTOXX		0.002	-0.049	-0.002	-0.003	-0.002
		(0.029)	(0.033)	(0.002)	(0.002)**	(0.001)**
Portfolio flows		0.016	0.003	0.012	0.026	0.012
		(0.007)**	(0.006)	(0.041)	(0.029)	(0.012)
Shadow rate		0.006	0.015	-0.003	0.014	-0.016
		(0.003)**	(0.006)**	(0.014)	(0.014)	(0.010)*
Volatility equation						
Constant		-12.122	-14.920	-8.041	-10.843	-4.213
		(1.787)***	(2.766)***	(0.924)***	(0.832)***	(1.172)***
L.ARCH		0.211	0.412	0.065	0.004	0.276
		(0.052)***	(0.124)***	(0.041)*	(0.032)	(0.083)***
L.GARCH		0.714	0.653	0.483	0.762	0.053
		(0.038)***	(0.071)***	(0.201)**	(0.088)***	(0.122)
VSTOXX		0.020	0.030	0.022	0.028	0.008
		(0.005)***	(0.008)***	(0.002)***	(0.002)***	(0.004)**
Shadow rate		0.044	0.671	0.118	0.039	0.365
		(0.074)	(0.079)***	(0.029)***	(0.029)*	(0.042)***
corr(Stock - Bond markets)	-0.045	0.029	0.003	-0.368	-0.243	-0.123
	(0.050)	(0.052)	(0.050)	(0.051)***	(0.042)***	(0.099)
corr(Stock - FX markets)		0.049	0.149	0.464	0.473	0.162
		(0.053)	(0.046)***	(0.046)***	(0.039)***	(0.093)*
corr(Bond - FX markets)		-0.021	-0.057	-0.547	-0.366	-0.337
		(0.061)	(0.052)	(0.041)***	(0.045)***	(0.105)***
Observations	523	466	523	523	523	523

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

With the objective of making our two continuous proxies as close as possible to the flow of asset purchases, we then examine the results of the DCC-MGARCH procedure when the measure obtained by resorting to the methodology originally proposed by Ahmed and Zlate (2014) – based on the impact that the outright purchase of financial assets has had on euro area AAA-rated 10-year government bond yields – is used as an alternative proxy for the ECB's non-standard programmes. Results of this battery of estimations are shown in **Table 4** and tend to reinforce our previous conclusions. The influence of this variable in affecting the *level* of asset returns in the *mean* equation remains limited, overall. As regards the impact on the *volatility* equation, estimation results tend to lead to the conclusion that the compression in euro area AAA-rated long-term government bond yields that can be ascribed to the implementation of the various ECB's APPs has been accompanied by a more contained volatility in EU-6 financial markets. The new proxy has the expected sign for all the countries in the sample in both the stock and the foreign exchange markets, and is statistically significant in four out of six cases in the former and in three out of five cases in the latter.[33] More importantly, the new proxy seems to be better suited to capture the effect on volatility in bond markets: contrary to what observed with the original measures (i.e. the actual euro area AAA-rated 10-year government bond yields), the coefficients now have the correct sign in four out of six cases, and they are statistically significant in half of the sample countries.

As regards the second refinement concerning the shadow rate, the strategy we intend to follow is to introduce an *ex-ante* cut-off date – the 9th of December 2011 – and to assess the likely existence of a differential – by sign, magnitude and/or significance level – impact of the continuous proxy on volatility developments in EU-6 financial markets before and after such an event. As already mentioned, this evaluation is performed by looking at the estimated coefficients of both the additive term $Dummy_{Dec.2011}$ and the interaction term $Dummy_{Dec.2011}$ x $Shadow\ rate_t$, which are intended to modify, respectively, the average level of, and the impact of the chosen proxy on, volatility in EU-6 financial markets before and after the occurrence of the December event. To make the research outcomes more robust, we also report the results of an *F*-test on these coefficients – with the null being that they are jointly not different from zero – which is intended to spot the existence of a structural break in the relationship under examination around the chosen cut-off date. Estimation outcomes of this further exercise are shown in **Table 5** and tend to confirm the hypothesis of a dampening effect exerted by the shadow rate on EU-6 financial markets volatility. As regards the stock markets, for instance, the results for Hungary and Romania clearly show the occurrence of a structural break around the December event, as suggested by the results of the *F*-test on the joint significance of the coefficients of both the indicator dummy and the interaction term. On the one hand, the interaction term $Dummy_{Dec.2011}$ x $Shadow\ rate_t$ takes on the expected positive sign and is statistically significant at conventional levels, in contrast with the insignificant coefficient of the non-interacted term $Shadow\ rate_t$ therefore demonstrating that our proxy started to exert a relevant trimming effect on the volatility of EU-6 countries' stock markets after the December cut-off date. On the other hand, the coefficient of the additive term $Dummy_{Dec.2011}$ comes out with a negative sign, suggesting that the period from December 2011 onwards has been characterised by a lower average volatility than the one prevailing in the preceding period. Although there appears to be no sign of a structural break in the expected direction for the other four countries in the sample, the conclusions about the favourable role played by the shadow rate in containing volatility spikes in EU-6 stock markets appears to be confirmed: independently from the occurrence of the December 2011 event, the coefficients of the term $Shadow\ rate_t$ always come out with the expected significant positive sign, the magnitude of which

[33] These results are the same as before for the foreign exchange market and marginally worsen for the equity markets, though not as much to radically change the overall conclusions about the favorable role played the ECB's APPs in containing volatility developments in these markets.

is larger than the (always insignificant) coefficients of the interaction terms *Dummy*$_{Dec.2011}$ *x Shadow rate*$_t$. Similar conclusions hold for the bond market as well. For the cases of Croatia, the Czech Republic, Hungary and, marginally, Bulgaria estimation results clearly point to the existence of a structural break in the relationship between the shadow rate and volatility developments. For these three countries, in fact, the coefficients of the interaction term *Dummy*$_{Dec.2011}$ *x Shadow rate*$_t$ turn out having the correct positive sign and being statistically significant, clearly pointing to the occurrence of a change in the relationship among the variables at stake especially when compared with the insignificant, or non-correctly signed, coefficients of the non-interacted term *Shadow rate*$_t$. Although the wrongly signed coefficients of the additive dummies would tend to signal an average higher volatility in the aftermath of the December event, their magnitude is relatively contained and not as large as to drastically change the conclusions about the dampening effect exerted by the shadow rate on volatility developments in this market. For the cases of Poland and Romania, on the contrary, there appears to be as well a structural change, although in the opposite direction with respect to the expected one; nevertheless, the magnitude of the coefficients of the term *Shadow rate*$_t$ is always larger than that of the interaction term *Dummy*$_{Dec.2011}$ *x Shadow rate*$_t$, therefore making the overall impact after the cut-off date still coherent with the general conclusion according to which the shadow rate has been helping to contain EU-6 bond market volatility. All in all, notwithstanding remaining estimation problems related to some countries and/or coefficients, we have been able likewise to take a step forward with respect to the rather unsatisfactory results obtained previously, since now in four out of six cases the relationship turns out as expected. As for the foreign exchange markets, in only two occasions (i.e. the Czech Republic and Hungary) there appears to be a clear structural break in the estimated relationship; nevertheless, adding the case of Romania – where again, independently from the occurrence of the December 2011 event, the coefficient of the term *Shadow rate*$_t$ always comes out with the expected significant positive sign while being larger than the (always insignificant) negative coefficient of the interaction terms – provides further support to the general conclusion about the role played by the shadow rate in containing volatility spikes in this market.

Overall, the results obtained by means of the DCC-MGARCH procedure tend to support our research hypothesis: the actual flow of financial asset purchases, along with the resulting dynamics of the euro area AAA-rated 10-year government bond yields or the shadow rate, seems to have been able to dampen the impact of adverse developments in global volatility, therefore shielding EU-6 financial markets from negative external shocks to international investors' degree of risk aversion. While our results are in line with those reported in Apostolou and Beirne (2017) as far as stock markets are concerned, we acknowledge the existence of a moderate departure – i.e. a more optimistic perspective about the role played by ECB's non-standard measures – as regards the foreign exchange and the long-term bond markets. Issues related to the estimation strategy – including the structure of the model – the use of a more comprehensive number of variables – including the control for global volatility developments – as well as our attention to a very particular non-standard monetary measure implemented by the ECB (i.e. the APPs) – with respect to the more general aspect of the changes in Central banks' balance sheet, which may depend on reasons quite apart from the actual implementation of asset purchases – may be called for as relevant explanations for the differences in the estimation results. As a concluding remark, we believe that the chosen econometric procedure has been able to provide favourable evidence about the existence of a "risk-taking" and a ("market" or "funding cash") "liquidity" channel of transmission related to the implementation of the different waves of APPs by the ECB since July 2009, which have helped to dampen volatility developments in EU-6 financial markets.

Table 4. DCC-MGARCH estimates: role of the impact of the APPs on euro area's AAA-rated government bond yields

	Bulgaria	Croatia	Czech Rep.	Hungary	Poland	Romania
Stock markets						
Mean equation						
Constant	5.677	3.378	6.089	3.890	3.625	4.423
	(1.081)***	(0.965)***	(1.843)***	(1.769)**	(1.427)***	(1.608)***
L.stock market returns	0.291	0.262	0.114	0.111	0.144	0.125
	(0.053)***	(0.070)***	(0.065)*	(0.058)**	(0.057)**	(0.059)**
VSTOXX	-0.018	-0.011	-0.020	-0.013	-0.011	-0.014
	(0.003)***	(0.003)***	(0.006)***	(0.006)**	(0.005)**	(0.005)**
Portfolio flows	-0.127	0.151	0.429	0.605	0.219	0.215
	(0.200)	(0.119)	(0.218)**	(0.256)**	(0.140)*	(0.082)***
APPs impact on AAA-rated bond yields	-0.069	-0.115	0.019	-0.316	0.019	0.122
	(0.088)	(0.073)*	(0.098)	(0.116)**	(0.105)	(0.122)
Volatility equation						
Constant	-3.271	-9.652	-6.832	-7.242	-5.412	-8.879
	(2.242)	(2.882)***	(1.543)***	(1.461)***	(1.200)***	(1.505)***
L.ARCH	0.258	0.177	0.261	0.114	0.098	0.150
	(0.083)***	(0.098)*	(0.112)**	(0.059)**	(0.062)*	(0.084)*
L.GARCH	0.450	0.654	0.219	0.475	0.147	0.203
	(0.127)***	(0.107)***	(0.196)	(0.195)**	(0.169)	(0.167)
VSTOXX	0.010	0.026	0.024	0.025	0.021	0.031
	(0.007)	(0.008)***	(0.005)***	(0.004)***	(0.004)***	(0.005)***
APPs impact on AAA-rated bond yields	0.376	0.441	0.067	0.279	0.019	0.370
	(0.243)*	(0.269)*	(0.120)	(0.140)**	(0.116)	(0.146)***
Bond markets						
Mean equation						
Constant	3.617	-10.963	1.561	-4.010	-1.616	-3.044
	(4.971)	(6.561)*	(6.432)*	(12.286)	(7.556)	(6.739)
L.bond yield changes	0.074	0.205	0.477	0.194	0.131	0.114
	(0.065)	(0.072)***	(0.073)***	(0.061)***	(0.055)**	(0.068)*
VSTOXX	-0.018	0.035	-0.009	0.002	0.039	0.008
	(0.016)	(0.021)*	(0.022)	(0.040)	(2.375)	(0.021)
Portfolio flows	-1.353	-0.647	0.068	-1.301	-1.061	-1.732
	(0.542)***	(0.426)*	(0.249)	(0.901)	(0.669)*	(0.710)**
APPs impact on AAA-rated bond yields	-0.841	0.008	-0.625	-3.005	-1.815	-0.539
	(0.556)*	(0.583)	(0.391)*	(0.887)***	(0.586)***	(1.222)
Volatility equation						
Constant	3.276	1.948	-8.033	-0.705	4.525	10.442
	(1.749)*	(4.621)	(15.647)	(1.672)	(2.980)	(66.739)
L.ARCH	0.392	0.555	0.190	0.225	0.064	0.275
	(0.210)*	(0.394)	(0.238)	(0.131)*	(0.034)*	(0.149)*
L.GARCH	0.087	0.437	0.623	0.412	0.861	0.745
	(0.144)	(0.346)	(0.940)	(0.273)	(0.049)***	(0.139)***
VSTOXX	0.009	0.004	0.034	0.018	-0.009	-0.031
	(0.005)*	(0.013)	(0.039)	(0.005)***	(0.010)	(0.225)
APPs impact on AAA-rated bond yields	0.347	0.190	0.728	0.505	-0.277	-0.394
	(0.194)*	(0.303)	(0.449)*	(0.240)**	(0.208)	(0.441)
FX markets						
Mean equation						
Constant		-0.019	0.125	0.714	0.381	0.545
		(0.100)	(0.096)	(0.671)	(0.588)	(0.277)**
L.FX returns		0.303	0.088	0.156	0.164	0.121
		(0.060)***	(0.073)	(0.053)***	(0.050)***	(0.030)***
VSTOXX		0.001	-0.032	-0.003	-0.001	-0.002
		(0.033)	(0.031)	(0.002)	(0.002)	(0.001)**
Portfolio flows		0.016	0.008	0.041	0.050	0.004
		(0.007)***	(0.005)*	(0.045)	(0.038)	(0.016)
APPs impact on AAA-rated bond yields		-0.001	0.014	-0.032	0.047	-0.019
		(0.016)	(0.009)*	(0.044)	(0.005)	(0.026)
Volatility equation						
Constant		-10.947	-19.441	-9.069	-9.934	-4.630
		(1.817)***	(3.305)***	(1.362)***	(1.175)***	(1.455)***
L.ARCH		0.206	0.462	0.015	-0.041	0.246
		(0.058)***	(0.138)***	(0.034)	(0.045)	(0.102)**
L.GARCH		0.708	0.537	0.640	0.443	-0.204
		(0.047)***	(0.074)***	(0.201)***	(0.157)***	(0.076)***
VSTOXX		0.017	0.052	0.025	0.028	0.010
		(0.006)***	(0.010)***	(0.003)***	(0.003)***	(0.005)**
APPs impact on AAA-rated bond yields		0.081	2.614	0.590	0.041	0.575
		(0.289)	(0.305)***	(0.108)***	(0.090)	(0.118)***
corr(Stock - Bond markets)	-0.046	-0.024	-0.019	-0.306	-0.247	-0.103
	(0.056)	(0.057)	0.076	(0.109)***	(0.049)***	(0.096)
corr(Stock - FX markets)		0.095	0.222	0.465	0.512	0.162
		(0.056)*	(0.051)***	(0.059)***	(0.043)***	(0.102)*
corr(Bond - FX markets)		0.009	-0.048	-0.515	-0.373	-0.360
		(0.059)	(0.083)	(0.078)***	(0.050)***	(0.153)**
Observations	393	393	393	393	393	393

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 5. DCC-MGARCH estimates: structural breaks in the relationship between EU-6 financial market volatility and the shadow rate

	Bulgaria	Croatia	Czech Rep.	Hungary	Poland	Romania
Stock markets						
Mean equation						
Constant	4.286	3.431	5.637	3.168	4.020	4.441
	(0.998)***	(0.860)***	(1.462)***	(1.456)**	(1.387)***	(1.221)***
L.stock market returns	0.289	0.313	0.143	0.130	0.152	0.156
	(0.048)***	(0.051)***	(0.056)***	(0.053)***	(0.051)***	(0.049)***
VSTOXX	-0.014	-0.011	-0.018	-0.010	-0.013	-0.014
	(0.003)***	(0.003)***	(0.005)***	(0.005)**	(0.005)***	(0.004)***
Portfolio flows	0.122	0.157	0.231	0.266	0.152	0.251
	(0.138)	(0.089)*	(0.108)**	(0.083)***	(0.113)*	(0.073)***
Shadow rate	-0.071	-0.055	-0.003	-0.073	-0.022	-0.001
	(0.032)**	(0.028)*	(0.031)	(0.035)**	(0.038)	(0.033)
Volatility equation						
Constant	-2.552	-9.524	-8.890	-5.457	-5.867	-6.466
	(1.511)*	(2.272)***	(1.207)***	(1.117)***	(1.249)***	(1.209)***
L.ARCH	0.267	0.082	0.235	-0.001	0.054	0.121
	(0.084)***	(0.113)	(0.084)***	(0.091)	(0.081)	(0.068)*
L.GARCH	0.388	0.836	0.239	0.220	0.263	0.087
	(0.171)**	(0.172)***	(0.163)	(0.252)	(0.264)	(0.117)
VSTOXX	0.011	0.024	0.030	0.022	0.021	0.025
	(0.005)**	(0.006)***	(0.003)***	(0.003)***	(0.003)***	(0.003)***
Shadow rate	0.225	0.407	0.134	-0.022	0.165	0.110
	(0.099)**	(0.192)**	(0.087)*	(0.056)	(0.065)***	(0.060)
Interaction term Dec. 2011	0.098	-0.290	0.047	0.174	-0.058	0.173
	(0.131)	(0.198)	(0.117)	(0.085)**	(0.089)	(0.090)**
Additive dummy Dec. 2011	-0.665	-0.425	0.433	-0.059	0.002	-0.286
	(0.374)*	(0.607)	(0.305)	(0.185)	(0.263)	(0.249)
Ho: No structural breaks	0.25	0.09	0.34	0.09	0.81	0.08
Bond markets						
Mean equation						
Constant	-3.400	-10.870	-4.040	-12.592	0.878	-3.509
	(5.305)	(5.431)**	(3.849)	(10.203)	(4.995)	(5.582)
L.bond yield changes	0.116	0.197	0.434	0.199	0.193	0.039
	(0.060)**	(0.066)***	(0.043)***	(0.053)***	(0.047)***	(0.061)
VSTOXX	0.009	0.036	0.012	0.039	-0.004	0.011
	(0.017)	(0.017)**	(0.012)	(0.033)	(0.016)	(0.018)
Portfolio flows	-0.423	-0.655	0.104	-1.168	-1.395	-1.746
	(0.505)	(0.390)*	(0.261)	(0.991)	(0.658)**	(0.586)***
Shadow rate	0.259	0.128	0.147	0.052	0.029	0.308
	(0.196)	(0.128)	(0.098)*	(0.261)	(0.171)	(0.226)
Volatility equation						
Constant	-0.954	-2.660	-3.069	-3.474	-1.545	-4.616
	(2.758)	(2.281)	(1.558)**	(1.194)***	(0.970)	(4.938)
L.ARCH	0.246	0.767	0.183	0.161	0.152	0.306
	(0.186)	(0.332)**	(0.093)*	(0.112)	(0.098)*	(0.199)*
L.GARCH	0.562	0.115	0.325	0.320	0.028	0.698
	(0.172)***	(0.159)	(0.262)	(0.240)	(0.101)	(0.148)***
VSTOXX	0.015	0.017	0.021	0.027	0.016	0.012
	(0.008)*	(0.006)**	(0.004)***	(0.003)***	(0.003)***	(0.016)
Shadow rate	-0.143	0.021	0.019	-0.133	0.073	1.101
	(0.213)	(0.141)	(0.081)	(0.088)	(0.074)	(0.293)***
Interaction term Dec. 2011	0.261	0.340	0.475	0.466	-0.044	-0.985
	(0.254)	(0.191)*	(0.124)***	(0.126)***	(0.102)	(0.324)***
Additive dummy Dec. 2011	-0.549	2.100	0.459	0.599	1.001	3.249
	(0.595)	(0.482)***	(0.348)	(0.307)**	(0.256)***	(1.068)***
Ho: No structural breaks	0.26	0.00	0.00	0.00	0.00	0.00
FX markets						
Mean equation						
Constant		-0.011	0.015	0.840	0.903	0.548
		(0.090)	(0.121)	(0.584)	(0.491)*	(0.242)**
L.FX returns		0.299	0.279	0.145	0.148	0.203
		(0.051)***	(0.033)***	(0.046)***	(0.044)***	(0.051)***
VSTOXX		0.000	0.000	-0.003	-0.003	-0.002
		(0.000)	(0.000)	(0.002)*	(0.002)*	(0.001)**
Portfolio flows		0.016	0.011	0.014	0.024	0.010
		(0.008)**	(0.010)	(0.044)	(0.035)	(0.013)
Shadow rate		0.006	0.005	-0.004	0.016	-0.006
		(0.003)**	(0.005)	(0.014)	(0.014)	(0.009)
Volatility equation						
Constant		-11.777	-7.844	-7.507	-11.756	-6.350
		(2.025)***	(1.287)***	(0.949)***	(1.079)***	(1.053)***
L.ARCH		0.214	0.356	0.024	-0.019	0.256
		(0.052)***	(0.093)***	(0.042)	(0.039)	(0.081)***
L.GARCH		0.708	0.548	0.439	0.742	0.037
		(0.040)***	(0.091)***	(0.174)***	(0.098)***	(0.128)
VSTOXX		0.020	0.022	0.021	0.032	0.014
		(0.005)***	(0.004)***	(0.002)***	(0.003)***	(0.003)***
Shadow rate		0.011	-0.013	0.010	-0.021	0.437
		(0.127)	(0.068)	(0.050)	(0.052)	(0.070)***
Interaction term Dec. 2011		-0.046	1.234	0.311	0.049	-0.062
		(0.179)	(0.110)***	(0.078)***	(0.070)	(0.137)
Additive dummy Dec. 2011		-0.379	0.256	0.170	-0.022	0.512
		(0.472)	(0.325)	(0.197)	(0.219)	(0.395)
Ho: No structural breaks		0.66	0.00	0.00	0.78	0.24
corr(Stock - Bond markets)	-0.038	-0.071	0.013	-0.348	-0.234	-0.132
	(0.041)	(0.048)	(0.051)	(0.061)***	(0.049)***	(0.105)
corr(Stock - FX markets)		0.079	0.158	0.451	0.481	0.163
		(0.052)	(0.049)***	(0.056)***	(0.048)***	(0.097)*
corr(Bond - FX markets)		-0.052	-0.041	-0.514	-0.345	-0.364
		(0.049)	(0.050)	(0.047)***	(0.052)***	(0.135)**
Observations	523	466	523	523	523	523

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

5. Robustness tests

To explore the sensitivity of the estimation results obtained by means of the DCC-MGARCH procedure to alternative specifications, and to confirm the conclusions reached thus far about the taming impact of the ECB's APPs on volatility developments in EU-6 economies, we conduct an extensive series of robustness checks, which are reported in the present section. Robustness tests are divided into two main categories: on the one hand, we adopt an alternative estimation methodology; on the other hand, we implement different changes in terms of underlying data generating process, proxies used to measure the impact of the ECB's APPs, dating of the presumed occurrence of structural breaks, new variables present in the volatility equation.

5.1 Alternative methodology

A first check relates to a simpler, though still instructive, approach borrowed by Converse (2015), which is based on the estimation of a series of country-by-country and market-by-market OLS regressions – similar, in structure and spirit, to those performed by means of the DCC-MGARCH model and reported in the previous section – where the dependent variable is now represented by the series of conditional volatilities estimated by means of the preferred AR(1)-GARCH(1,1) process presented in Appendix I. The estimated models now take the following form:

$$\ln\left(\sigma_{it}^{j}\right) = c + \beta_1 VSTOXX_t + \beta_2 ECB's\ APPs_t + \epsilon_t \quad (10)$$

where $\ln\left(\sigma_{it}^{j}\right)$ represents (the natural log of) the AR(1)-GARCH(1,1) conditional variance of the weekly asset returns for each financial market *j* in each of the EU-6 country *i*.[34] As in the DCC-MGARCH exercise, developments in conditional volatilities are supposed to be related mainly to two variables, $VSTOXX_t$ and $ECB's\ APPs_t$, which again gather together the three different proxies related to the ECB's asset purchase programmes. While acknowledging that developments in financial markets volatility might also depend on other variables (Bekaert and Harvey, 1997; Converse, 2015), we decided to constrain ourselves to relying only on these two factors, as we intend to compare the results of the current exercise with those stemming from the use of the DCC-MGARCH procedure of the previous section. Moreover, to remain coherent with that approach, we exactly replicate the same steps as before: a simple specification with no role for the proxies of the impact of APPs, their subsequent introduction in the model on an individual basis and, finally, the consideration of the two refinements needed to make the two continuous proxies as close as possible to the actual flow of financial asset purchases.

Overall, the results of this first battery of robustness tests, contained in **Tables 6-9**, tend to confirm those obtained by means of the DCC-MGARCH procedure. After controlling for the impact of external shocks on global volatility, there appears to be a dampening impact on volatility in EU-6 financial markets stemming from the implementation of the ECB's APPs: the expected relationships between our proxies for non-standard monetary policy and volatility developments in EU-6 financial markets, as well as their statistical significance at conventional levels, hold in an overwhelming number of cases and independently from the chosen model specification. When we introduce the refinements used to ensure that the two continuous proxies are as close as possible to the flow of asset purchases, the previous results are also confirmed. The reduction in euro area AAA-rated long-term government bond yields that can be accounted for by the implementation of ECB's actual asset

[34] Using the logarithm of the conditional volatility makes it possible to interpret the estimated coefficient as the response in percentage changes to movements in the independent variables.

purchases has been accompanied by a more contained volatility in EU-6 financial markets.[35] When considering the introduction of the two additive and interaction dummies related to the 9th of December 2011 cut-off date, it is worth underscoring that there appears to be an even larger number of cases – as compared with the estimations obtained with the DCC-MGARCH procedure – in which the results point to the existence of a clear structural break in the relationship between the shadow rate and volatility developments in the three markets considered, as witnessed by the F-tests on the coefficient δ_1 of the indicator dummy and δ_2 of the interaction term of equation (11):

$$\ln\left(\sigma_{it}^{j}\right) = c + \beta_2 VSTOXX_t + \beta_3 ECB'sAPPs_t + \delta_1 Dummy_\tau + \delta_2 Dummy_\tau * ECB's\ APPs_t + \epsilon_t \quad (11)$$

Table 6. OLS estimates: initial specification

		Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania
Stock markets							
	Constant	-3.123	-14.645	-13.859	-11.938	-12.913	-14.399
		(0.506)***	(0.439)***	(0.297)***	(0.256)***	(0.259)***	(0.278)***
	VSTOXX	**0.014**	**0.020**	**0.019**	**0.014**	**0.016**	**0.022**
		(0.002)*	**(0.001)***	**(0.001)***	**(0.001)***	**(0.001)***	**(0.001)***
	Observations	524	524	524	524	524	524
	R-squared (adj.)	0.22	0.31	0.54	0.52	0.44	0.51
Bond markets							
	Constant	0.962	-7.142	-9.708	-7.758	-6.212	-7.279
		(0.426)**	(0.609)***	(0.334)***	(0.346)***	(0.284)***	(0.609)***
	VSTOXX	**0.012**	-0.003	**0.015**	**0.014**	**0.005**	**0.010**
		(0.001)*	(0.002)	**(0.001)***	**(0.001)***	**(0.001)***	**(0.002)***
	Observations	524	467	524	524	524	491
	R-squared (adj.)	0.18	0.00	0.28	0.26	0.09	0.07
FX markets							
	Constant		-15.394	-18.398	-13.957	-15.047	-14.573
			(0.336)***	(0.689)***	(0.269)***	(0.292)***	(0.406)***
	VSTOXX		**0.009**	**0.024**	**0.015**	**0.018**	**0.013**
			(0.001)*	**(0.002)***	**(0.001)***	**(0.001)***	**(0.001)***
	Observations		524	524	524	524	524
	R-squared (adj.)		0.15	0.16	0.38	0.53	0.20

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

[35] This result seems to be sufficiently general across markets and countries with only three exceptions represented by the long-term government bond markets in Croatia and Poland, and the foreign exchange market in Croatia.

Table 7.a OLS estimates: role of the flow of asset purchases

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania
Stock markets						
Constant	-0.549	-14.051	-12.100	-10.937	-12.161	-14.338
	(0.373)	(0.371)***	(0.394)***	(0.240)***	(0.348)***	(0.350)***
VSTOXX	**0.006**	**0.018**	**0.014**	**0.011**	**0.013**	**0.022**
	(0.001)* **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
ECB's asset purchases	**-0.035**	**-0.052**	**-0.003**	**-0.008**	**-0.005**	**-0.038**
	(0.004)* **	**(0.004)*** **	**(0.004)**	**(0.003)*** **	**(0.004)* **	**(0.004)*** **
Observations	393	393	393	393	393	393
R-squared (adj.)	0.14	0.39	0.31	0.34	0.31	0.51
Bond markets						
Constant	3.399	-5.398	-9.524	-5.829	-3.949	-4.258
	(0.405)***	(0.660)***	(0.536)***	(0.337)***	(0.230)***	(0.699)***
VSTOXX	**0.005**	-0.008	**0.014**	**0.008**	-0.003	**0.001**
	(0.001)* **	(0.002)***	**(0.002)*** **	**(0.001)*** **	(0.001)***	**(0.002)**
ECB's asset purchases	**-0.024**	0.020	**-0.051**	**-0.041**	0.009	**-0.024**
	(0.004)* **	(0.008)**	**(0.005)*** **	**(0.004)*** **	(0.003)***	**(0.007)*** **
Observations	393	393	393	393	393	393
R-squared (adj.)	0.07	0.04	0.33	0.22	0.04	0.02
FX markets						
Constant		-14.117	-18.700	-13.696	-13.957	-12.518
		(0.413)***	(0.856)***	(0.267)***	(0.257)***	(0.329)***
VSTOXX		**0.005**	**0.027**	**0.014**	**0.014**	**0.006**
		(0.001)* **	**(0.003)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
ECB's asset purchases		0.002	**-0.204**	**-0.057**	**-0.008**	**-0.036**
		(0.005)	**(0.010)*** **	**(0.003)*** **	**(0.003)*** **	**(0.004)*** **
Observations		393	393	393	393	393
R-squared (adj.)		0.03	0.60	0.58	0.42	0.18

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 7.b OLS estimates: role of euro area's AAA-rated government bond yields

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania
Stock markets						
Constant	-2.611	-13.871	-13.760	-11.817	-12.651	-13.931
	(0.442)***	(0.304)***	(0.290)***	(0.246)***	(0.233)***	(0.218)***
VSTOXX	**0.010**	**0.014**	**0.019**	**0.013**	**0.014**	**0.018**
	(0.001)* **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
AAA-rated bond yields	**0.347**	**0.525**	**0.067**	**0.082**	**0.178**	**0.317**
	(0.000)* **	**(0.014)*** **	**(0.018)*** **	**(0.013)*** **	**(0.016)*** **	**(0.014)*** **
Observations	524	524	524	524	524	524
R-squared (adj.)	0.47	0.74	0.55	0.55	0.54	0.73
Bond markets						
Constant	1.075	-8.196	-9.410	-7.648	-6.349	-6.635
	(0.421)***	(0.608)***	(0.327)***	(0.341)***	(0.285)***	(0.627)***
VSTOXX	**0.011**	**0.003**	**0.012**	**0.013**	**0.006**	**0.007**
	(0.001)* **	**(0.002)**	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.002)*** **
AAA-rated bond yields	**0.076**	-0.278	**0.202**	**0.075**	-0.093	**0.196**
	(0.020)* **	(0.037)***	**(0.019)*** **	**(0.022)*** **	(0.011)***	**(0.037)*** **
Observations	524	467	524	524	524	491
R-squared (adj.)	0.20	0.10	0.40	0.27	0.17	0.11
FX markets						
Constant		-15.284	-17.108	-13.607	-14.940	-14.097
		(0.322)***	(0.536)***	(0.229)***	(0.279)***	(0.347)***
VSTOXX		**0.008**	**0.013**	**0.012**	**0.017**	**0.009**
		(0.001)* **	**(0.002)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
AAA-rated bond yields		**0.074**	**0.874**	**0.237**	**0.072**	**0.323**
		(0.021)* **	**(0.046)*** **	**(0.014)*** **	**(0.015)*** **	**(0.017)*** **
Observations		524	524	524	524	524
R-squared (adj.)		0.17	0.59	0.58	0.55	0.46

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 7.c OLS estimates: role of the shadow rate

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania
Stock markets						
Constant	-2.625	-13.980	-13.777	-11.859	-12.675	-13.952
	(0.436)***	(0.374)***	(0.288)***	(0.247)***	(0.239)***	(0.230)***
VSTOXX	**0.013**	**0.018**	**0.019**	**0.014**	**0.016**	**0.020**
	(0.001)* **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
Shadow rate	**0.186**	**0.250**	**0.031**	**0.030**	**0.089**	**0.167**
	(0.010)* **	**(0.009)*** **	**(0.010)*** **	**(0.007)*** **	**(0.009)*** **	**(0.008)*** **
Observations	524	524	524	524	524	524
R-squared (adj.)	0.44	0.60	0.54	0.53	0.52	0.69
Bond markets						
Constant	1.010	-7.974	-9.438	-7.721	-6.323	-6.800
	(0.428)***	(0.625)***	(0.330)***	(0.349)***	(0.285)***	(0.616)***
VSTOXX	**0.012**	0.000	**0.014**	**0.014**	**0.005**	**0.009**
	(0.001)* **	(0.002)	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.002)*** **
Shadow rate	**0.018**	-0.118	**0.101**	**0.014**	-0.042	**0.078**
	(0.012)	(0.021)***	**(0.012)*** **	**(0.013)**	(0.007)***	**(0.019)*** **
Observations	524	467	524	524	524	491
R-squared (adj.)	0.18	0.05	0.37	0.26	0.14	0.08
FX markets						
Constant		-15.363	-17.192	-13.703	-15.057	-14.000
		(0.335)***	(0.625)***	(0.262)***	(0.293)***	(0.331)***
VSTOXX		**0.009**	**0.020**	**0.014**	**0.018**	**0.011**
		(0.001)* **	**(0.002)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
Shadow rate		**0.012**	**0.452**	**0.095**	-0.004	**0.215**
		(0.011)	**(0.128)*** **	**(0.010)*** **	(0.009)	**(0.009)*** **
Observations		524	524	524	524	524
R-squared (adj.)		0.15	0.51	0.47	0.53	0.54

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 8. OLS estimates: role of the impact of the APPs on euro area's AAA-rated government bond yields

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania
Stock markets						
Constant	-0.568	-14.038	-12.136	-10.965	-12.224	-14.356
	(0.367)	(0.377)***	(0.348)***	(0.237)***	(0.343)***	(0.342)***
VSTOXX	**0.006**	**0.018**	**0.014**	**0.011**	**0.014**	**0.022**
	(0.001)* **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
APPs impact on AAA-rated bond yields	**0.316**	**0.457**	**0.054**	**0.092**	**0.075**	**0.349**
	(0.035)* **	**(0.032)*** **	**(0.034)* **	**(0.023)*** **	**(0.030)*** **	**(0.029)*** **
Observations	392	392	392	392	392	392
R-squared (adj)	0.15	0.39	0.31	0.34	0.32	0.52
Bond markets						
Constant	3.432	-5.323	-9.517	-5.821	-3.987	-4.249
	(0.414)***	(0.648)***	(0.529)***	(0.336)***	(0.231)***	(0.677)***
VSTOXX	**0.005**	-0.009	**0.014**	**0.008**	-0.003	**0.001**
	(0.001)* **	(0.002)***	**(0.002)*** **	**(0.001)*** **	(0.001)***	**(0.002)**
APPs impact on AAA-rated bond yields	**0.204**	-0.171	**0.451**	**0.370**	-0.068	**0.204**
	(0.033)* **	(0.072)**	**(0.038)*** **	**(0.033)*** **	(0.024)***	**(0.057)*** **
Observations	392	392	392	392	392	392
R-squared (adj)	0.06	0.04	0.33	0.23	0.04	0.02
FX markets						
Constant		-14.096	-18.496	-13.691	-13.957	-12.503
		(0.414)***	(0.856)***	(0.268)***	(0.259)***	(0.326)***
VSTOXX		**0.005**	**0.027**	**0.014**	**0.014**	**0.006**
		(0.001)* **	**(0.003)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
APPs impact on AAA-rated bond yields		-0.023	**1.752**	**0.497**	**0.081**	**0.304**
		(0.042)	**(0.091)*** **	**(0.025)*** **	**(0.023)*** **	**(0.033)*** **
Observations		392	392	392	392	392
R-squared (adj)		0.03	0.60	0.59	0.42	0.17

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

Table 9. OLS estimates: structural breaks in the relationship between EU-6 financial market volatility and the shadow rate

	Bulgaria	Croatia	Czech Republic	Hungary	Poland	Romania
Stock markets						
Constant	-1.738	-11.929	-13.770	-11.073	-12.720	-13.226
	(0.456)***	(0.296)***	(0.355)***	(0.332)***	(0.272)***	(0.268)***
VSTOXX	**0.011**	**0.014**	**0.019**	**0.012**	**0.016**	**0.019**
	(0.001)* **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
Shadow rate	**0.097**	**0.029**	**0.033**	-0.057	**0.100**	**0.077**
	(0.026)* **	**(0.024)**	**(0.021)* **	(0.016)***	**(0.021)*** **	**(0.019)*** **
Interaction term Dec. 2011	**0.014**	**0.095**	-0.009	**0.098**	-0.028	**0.085**
	(0.035)	**(0.028)*** **	(0.031)	**(0.019)*** **	(0.028)	**(0.026)*** **
Additive dummy Dec. 2011	**-0.550**	**-1.177**	**-0.012**	**-0.275**	**-0.012**	**-0.341**
	(0.097)* **	**(0.086)*** **	**(0.080)**	**(0.059)*** **	**(0.077)**	**(0.078)*** **
Ho: No Structural Break	**0.00**	**0.00**	0.95	**0.00**	0.56	**0.00**
Observations	524	524	524	524	524	524
R-squared (adj.)	0.47	0.73	0.54	0.57	0.52	0.71
Bond markets						
Constant	2.673	-10.292	-9.647	-7.685	-6.730	-5.710
	(0.479)***	(0.666)***	(0.348)***	(0.358)***	(0.318)***	(0.874)***
VSTOXX	**0.008**	**0.006**	**0.015**	**0.014**	**0.006**	**0.006**
	(0.001)* **	**(0.002)** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **	**(0.002)*** **
Shadow rate	-0.164	-0.035	**0.007**	-0.131	-0.005	-0.064
	(0.028)***	(0.027)	**(0.021)**	(0.023)***	(0.014)	(0.052)
Interaction term Dec. 2011	**0.205**	**0.114**	**0.349**	**0.457**	**0.011**	**0.170**
	(0.035)* **	**(0.047)*** **	**(0.030)*** **	**(0.033)*** **	**(0.023)**	**(0.058)*** **
Additive dummy Dec. 2011	**-0.584**	1.028	0.432	0.420	0.278	**-0.391**
	(0.106)* **	(0.131)***	(0.084)***	(0.089)***	(0.056)***	**(0.194)** **
Ho: No Structural Break	**0.00**	**0.00**	**0.00**	**0.00**	0.00	**0.01**
Observations	524	467	524	524	524	524
R-squared (adj.)	0.26	0.13	0.49	0.45	0.18	0.11
FX markets						
Constant		-14.426	-14.306	-12.542	-13.597	-14.287
		(0.342)***	(0.523)***	(0.268)***	(0.290)***	(0.390)***
VSTOXX		**0.007**	**0.015**	**0.011**	**0.014**	**0.012**
		(0.001)* **	**(0.002)*** **	**(0.001)*** **	**(0.001)*** **	**(0.001)*** **
Shadow rate		-0.094	-0.088	-0.108	-0.153	**0.251**
		(0.025)***	(0.025)***	(0.015)***	(0.016)***	**(0.021)*** **
Interaction term Dec. 2011		**0.126**	**1.116**	**0.389**	**0.147**	-0.051
		(0.035)* **	**(0.051)*** **	**(0.022)*** **	**(0.021)*** **	(0.029)*
Additive dummy Dec. 2011		**-0.319**	**-0.199**	**-0.172**	**-0.545**	0.086
		(0.093)* **	**(0.117)* **	**(0.059)*** **	**(0.060)*** **	(0.094)
Ho: No Structural Break		**0.00**	**0.00**	**0.00**	**0.00**	0.12
Observations		524	524	524	524	524
R-squared (adj.)		0.18	0.74	0.66	0.61	0.54

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1; Ho tests the presence of a structural break in correspondence of July 2009 and October 2014; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.

While so far our attention has been devoted to inspecting the relationship between the implementation of the ECB's APPs and volatility developments in EU-6 financial markets on a country-by-country basis, the use of the estimated series of conditional volatilities also allow us to enlarge our analysis to a region-wide perspective. To do so, we follow again Converse (2015) in running a series of fixed-effect unbalanced panel regressions; the results of this latter exercise are shown in **Tables 10-12**, and broadly confirm those obtained previously on an individual basis. In this respect, we can conclude that the expected relationship between the estimated conditional volatilities and our proxies for the ECB's non-standard measures hold, on average, for all the markets but the long-term government bond one, where the coefficients of the three proxies (though correctly signed) never come out statistically significant. Nevertheless, the use of the two refinements helps to overcome this apparent odd result: when introducing the measure of euro area AAA-rated long-term government bond yields derived from the Ahmed and Zlate's (2014) procedure or the additive and interaction dummies for the shadow rate, the working of the relationship between the two proxies and volatility developments in EU-6 financial markets is significantly reinforced and confirmed, including for the bond market.

Table 10. Country fixed-effects OLS panel estimates: role of the different proxies for ECB's APPs

	Stock markets				Bond markets				FX markets			
Constant	-11.813	-10.689	-11.440	-11.478	-6.159	-4.260	-6.086	-6.116	-6.159	-15.294	-15.136	-15.177
	(0.417)***	(0.390)***	(0.690)***	(0.393)***	(0.843)**	(0.997)**	(0.720)***	(0.751)***	(0.843)***	(0.921)***	(0.524)***	(0.521)***
VSTOXX	**0.018**	**0.014**	**0.015**	**0.017**	**0.009**	**0.003**	**0.008**	**0.009**	**0.016**	**0.015**	**0.012**	**0.014**
	(0.001)* **	**(0.002)*** **	**(0.002)*** **	**(0.124)*** **	**(0.003)** **	**(0.003)**	**(0.002)** **	**(0.002)** **	**(0.002)*** **	**(0.003)*** **	**(0.001)*** **	**(0.002)*** **
ECB's asset purchases		**-0.024**				**-0.019**				**-0.059**		
		(0.009) **				**(0.011)**				**(0.027)***		
AAA-rated bond yields			**0.253**				**0.035**				**0.358**	
			(0.072) **				**(0.070)**				**(0.112)** **	
Shadow rate				**0.125**				**0.011**				**0.183**
				(0.037) **				**(0.030)**				**(0.067)** **
Observations	3,144	2,358	3,144	3,144	3,054	2,358	3,054	3,054	3,668	2,751	3,668	3,668
R-squared (adj.)	0.38	0.28	0.55	0.50	0.09	0.02	0.09	0.09	0.20	0.25	0.40	0.36

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1.

Table 11. Country fixed-effects OLS panel estimates: role of the impact of the flows of asset purchases on euro area's AAA-rated long-term government bond yields

	Stock markets	Bond markets	FX markets
Constant	-10.715	-4.566	-15.255
	(0.688)**	(0.677)***	(0.901)***
VSTOXX	**0.014**	**0.002**	**0.015**
	(0.002)* **	**(0.002)**	**(0.003)*** **
APPs impact on AAA-rated bond yields	**0.224**	**0.117**	**0.507**
	(0.070) **	**(0.067)***	**(0.227)***
Observations	2,352	2,352	2,744
R-squared (adj.)	0.29	0.02	0.25

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1.

Table 12. Country fixed-effects OLS panel estimates: structural breaks in the relationship between EU-6 financial market volatility and the shadow rate

	Stock markets	Bond markets	FX markets
Constant	-10.640	-5.704	-13.985
	(0.508)***	(0.525)***	(0.570)***
VSTOXX	**0.015**	**0.008**	**0.012**
	(0.001)* **	**(0.002)** **	**(0.002)*** **
Shadow rate	**0.055**	-0.082	**0.007**
	(0.026)*	(0.039)*	**(0.083)**
Interaction term Dec. 2011	**0.036**	**0.189**	**0.257**
	(0.023)	**(0.068)** **	**(0.152)***
Additive dummy Dec. 2011	**-0.359**	**-0.017**	**-0.385**
	(0.153)*	**(0.274)**	**(0.145)*** **
Ho: No Structural Break	**0.15**	**0.09**	**0.04**
Observations	3,144	3,054	3,668
R-squared (adj.)	0.52	0.12	0.40

Note: Huber-White heteroskedasticity consistent standard errors are provided in parenthesis, ***p<0.01, **p<0.05, *p<0.1.

5.2 Other checks

In order to square further our results, we conducted an extensive series of other, minor, robustness tests. First of all, we replicated some of the estimation exercises by introducing other measures describing the impact of *unconventional* monetary policies, which have already been used in the existing literature: i) in the regressions contained in Table 3.b, we substituted the euro area 10-year AAA-rated government bond yield with the term spread (Cerutti *et al.*, 2014; IMF, 2016), calculated as the difference between the 10-year and 3-month AAA-rated government bond yields; ii) in the regressions contained in Table 4, we replaced the impact of the ECB's APPs on euro area 10-year AAA-rated government bond yields with that on the term spread; iii) in the regressions contained in Table 3.c and Table 5, we used, instead of the shadow rate, its difference with respect to the ECB's main refinancing rate (Albertazzi *et al.*, 2016). Secondly, we considered a change in the date of the structural break for the shadow rate, experimenting with the 3rd of October 2014 instead of the 9th of December 2011. This alternative cut-off date is chosen to stick exactly to the Federal Reserve's approach: around this date, the key operational details of both the asset-backed securities purchase programme and the covered bond purchase programme were made public, while the ECB's main refinancing interest rate just hit the zero lower bound. Thirdly, we experimented with different hypotheses about the underlying data generating processes: since the GARCH component often turns out not to be significant in the different DCC-MGARCH regressions, we re-estimated the regressions by taking into account only the ARCH component; at the same time, we also re-run the OLS specifications by using, as a dependent variable, the series of conditional volatilities estimated under the hypothesis of an underlying simpler AR(1)-ARCH(1) process. Finally, we tried to augment the series of factors affecting the *volatility* equation in both the DCC-MGARCH and the OLS approaches by introducing both the capital flows and their volatility as new explanatory variables. Overall, the results of these further series of robustness tests tend to be broadly consistent and coherent with those contained in the main tables.[36]

6. Conclusions and policy implications

In this paper, we shed some light on the question of whether, and to what extent, the different waves of asset purchase programmes the ECB has been implementing since July 2009 may have contributed to protecting EU-6 financial markets from the adverse shocks that have been hitting international investors' degree of risk aversion in recent years. After building a large dataset for weekly stock and foreign exchange returns and long-term bond yield changes, we relied upon the DCC-MGARCH procedure to answer our research question, using three different proxies to describe the functioning and the impact of the ECB's APPs. Overall, irrespective of the measurement method, estimation outcomes clearly show that such non-standard monetary initiatives contributed to the taming of volatility developments in EU-6 stock, long-term government bond and foreign exchange markets, evidence which may be thought of as reflecting the working of a "risk taking" and a (market or funding cash) "liquidity" channel of transmission. Our results, which are robust to an extensive series of tests, may have important implications. Looking forward, in fact, it could not be ruled out that the process of gradual re-calibration of the monetary stance by the ECB could be accompanied by an increase in volatility in EU-6 financial markets. Measures to limit adverse volatility spillovers may include, but are not limited to, altering monetary and fiscal policies where policy space is available, as well as exchange rate and foreign exchange reserves management.

[36] For the sake of brevity, results of this battery of robustness tests are not reported here, though they are available from the authors upon request.

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Appendix I. Statistical properties of the series of asset price changes

In this Appendix, we perform a set of statistical tests on the series of EU-6 financial asset returns. More precisely, we use a multi-pronged strategy to gauge which statistical model fits the data best: first, we check for the existence of unit roots in the available series; second, we estimate a GARCH(1,1) model for the data generating process (DGP); as a final control, we compare actual with fitted data.

In order to check for the existence of unit roots, we perform a typical augmented Dickey-Fuller (ADF) test. To do so, we run a regression that takes into account an AR(1) component in the DGP of all the EU-6 financial markets asset price series as well as their first differences, calculated as weekly changes. The results of this battery of tests are reported in **Table 1.A**: unit roots seem to be present in the overwhelming majority of cases when looking at the series in levels; on the contrary, the respective weekly changes clearly appear to be stationary in all the instances.[37]

Once ascertained about the stationarity question, **Table 2.A** contains some key statistics related to the series of the weekly changes in the local currency-denominated stock market index, the yield on local-currency denominated 10-year government bonds and the foreign exchange rate *vis-à-vis* the euro. Weekly changes in EU-6 financial asset returns appear in general rather contained, especially so for the stock market case.

Provided that the week-on-week changes in EU-6 asset return series follow an AR(1) process, we check for the presence of any ARCH process. To do so, we follow the procedure initially proposed by Engle (1982) and based on the Breusch-Pagan Lagrange multiplier (LM) test, the results of which are contained in **Table 3.A**: in the overwhelming majority of the cases, the null hypothesis of an ARCH(1) process cannot be rejected.[38] At the same time, it has to be noted that the presence of ARCH(1) components does not rule out *per se* the existence of higher order ARCH elements, which are at stake in a handful of EU-6 financial markets.[39]

In view of these results, and given the vast popularity of GARCH(1,1) models in empirical application in finance (Poon and Granger, 2003) due to their relative parsimony and flexibility with respect to higher order ARCH models (Bollerslev, 1986) and their success in forecasting conditional volatility (Engle, 2001), we decided to estimate an AR(1)-GARCH(1,1) model separately for each country and market, according to the following specifications:[40]

$$\Delta r_t = \rho_0 + \rho_1 \Delta r_{t-1} + \varepsilon_t \quad (1)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (2)$$

In the formulas, Δr_t represents the weekly changes in EU-6 long-term government bond yields, the stock market indices and exchange rates *vis-à-vis* the euro, respectively; ρ_1 is the autoregressive

[37] The ADF test has non-standard threshold values for the t-statistic used to test the null hypothesis. Such statistic changes according to the specification of the process under the null, i.e. whether it is a random walk with or without trend or drift. Therefore, we made a preliminary visual inspection of the time evolution of the data before deciding which DGP fitted the data best to run the ADF test.

[38] We also perform a second series of Breusch-Pagan LM tests to verify the presence of ARCH(1) elements in the data when the DGP does not contain an AR(1) term finding no major differences between the two DGPs. Results are available from the authors upon request.

[39] Results of these higher order Breusch-Pagan LM tests are available from the authors upon requests.

[40] We also run a series of more formal tests on the three markets at stake in each country, namely the AIC and the BIC, to determine the best structure for the model. We found that, in the overwhelming majority of cases (i.e., more than 75% for both the AIC the BIC tests), the AR(1)-GARCH(1,1) model performs the best job. Results are available from the authors upon request.

parameter, α_1 the ARCH term and β_1 the GARCH term. Results of these regressions, contained in **Table 4.A**, would suggest that the AR(1)-GARCH(1,1) specification fits the data pretty well. In greater detail: i) apart from the long-term yield changes in Romania, asset price returns display strong autoregressive behaviour; ii) both the ARCH and the GARCH terms are significant across countries and markets, with just minor exceptions;[41] iii) the sum of the α_1 and β_1 terms, which signals the persistence of the process, is almost always strictly less than one, suggesting that in the long-run the conditional variance converges to the unconditional variance (Engle, 2001).[42]

Charts 1.A to **3.A** compare developments in both the unconditional and the conditional volatility series for all EU-6 financial markets.[43] In general, the charts seem to indicate that the two series tend to move closely together; this is also confirmed by sounder analytical means. Though being a simple measure, the correlation coefficient between the conditional and the unconditional volatility series strengthens the findings of Charts 5–7. Even though varying according to the market at stake, such coefficient is in fact rather high on average: while it hovers around 90% for both the stock and the foreign exchange market returns series, it displays a higher dispersion for long-term government bond yield changes, ranging between 56% for Croatia and 90% for Hungary and Poland.

[41] The yield changes series of Croatia and the Czech Republic and the stock market returns series of Bulgaria.

[42] These equations were also run without the AR(1) term. Results, available from the authors upon request, are in general consistent with those reported in the main text.

[43] Unconditional volatility is calculated as the annualised 12-week rolling standard deviation of the weekly asset price returns/changes, while conditional volatility is instead worked out as the square root of the residuals from the AR(1)-GARCH(1,1) specifications.

Table 1.A Asset price levels and weekly changes: augmented Dickey Fuller test

	Levels				Week on week changes			
Stock market indices								
	AR(1) Coeff.	S.E.	ADF Stat.	p-value	AR(1) Coeff.	S.E.	ADF Stat.	p-value
Bulgaria	0.995	0.002	-2.265	(0.184)	0.445	0.049	-11.422***	(0.000)
Croatia	0.996	0.003	-1.462	(0.552)	0.401	0.050	-12.088***	(0.000)
Czech Republic	0.992	0.004	-1.876	(0.344)	0.196	0.056	-14.457***	(0.000)
Hungary	0.996	0.006	-0.773	(0.968)	0.198	0.055	-14.504***	(0.000)
Poland	0.991	0.005	-1.745	(0.408)	0.213	0.056	-14.172***	(0.000)
Romania	0.992	0.004	-1.813	(0.374)	0.312	0.053	-12.922***	(0.000)
Long-term bond yields								
	AR(1) Coeff.	S.E.	ADF Stat.	p-value	AR(1) Coeff.	S.E.	ADF Stat.	p-value
Bulgaria	0.986	0.006	-2.434	(0.362)	-0.107	0.062	-17.750***	(0.000)
Croatia	0.982	0.008	-2.416	(0.371)	0.181	0.062	-13.309***	(0.000)
Czech Republic	0.978	0.006	-3.531**	(0.036)	0.340	0.047	-14.144***	(0.000)
Hungary	0.980	0.008	-2.661	(0.252)	0.140	0.057	-14.957***	(0.000)
Poland	0.984	0.006	-2.548	(0.304)	0.211	0.055	-14.396***	(0.000)
Romania	0.976	0.007	-3.195*	(0.085)	0.062	0.064	-14.616***	(0.000)
Exchange rate *vis-a-vis* the euro								
	AR(1) Coeff.	S.E.	ADF Stat.	p-value	AR(1) Coeff.	S.E.	ADF Stat.	p-value
Bulgaria	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Croatia	0.991	0.005	-1.716	(0.423)	0.202	0.053	-14.977***	(0.000)
Czech Republic	0.986	0.007	-2.193	(0.209)	0.091	0.056	-16.100***	(0.000)
Hungary	0.952	0.013	-3.718**	(0.021)	0.068	0.059	-15.802***	(0.000)
Poland	0.978	0.009	-2.522	(0.317)	0.127	0.059	-14.837***	(0.000)
Romania	0.989	0.006	-1.963	(0.621)	0.188	0.054	-15.085***	(0.000)

Note: authors' calculations.

Table 2.A Asset price weekly changes: summary statistics

	Stock market indices (in percent)				Long-term bond yields (in basis points)				Exchange rate *vis-à-vis* the euro (in percent)			
	Mean	St. Dev.	Min.	Max.	Mean	St. Dev.	Min.	Max.	Mean	St. Dev.	Min.	Max.
Bulgaria	-0.14	2.98	-25.51	14.17	-0.43	13.20	-82.10	106.90	0.00	0.03	-0.41	0.40
Croatia	-0.08	2.53	-16.18	11.11	-0.61	12.00	-60.30	108.10	-0.01	0.23	-1.09	0.93
Czech Republic	-0.10	2.73	-16.25	13.47	-0.63	9.53	-60.70	41.00	0.00	0.72	-3.03	3.91
Hungary	0.06	2.91	-17.62	9.46	-0.64	22.94	-146.40	142.00	-0.04	1.08	-4.98	5.20
Poland	0.01	2.48	-12.76	9.30	-0.29	9.99	-39.30	56.10	-0.02	1.06	-5.47	3.56
Romania	-0.03	3.06	-16.51	10.90	-0.69	17.96	-110.00	84.70	-0.05	0.70	-3.78	4.29

Note: authors' calculations.

Table 3.A LM ARCH(1) test on AR(1) Data Generating Process

	Stock market indices		Long-term bond yields		Exchange rate *vis-a-vis* the euro	
	χ2 - Stat.	p-value	χ2 - Stat.	p-value	χ2 - Stat.	p-value
Bulgaria	50.222***	(0.000)	2.433	(0.119)	n.a.	n.a.
Croatia	63.369***	(0.000)	4.231**	(0.039)	26.233***	(0.000)
Czech Republic	35.851***	(0.000)	9.349***	(0.002)	55.255***	(0.000)
Hungary	39.375***	(0.000)	5.397**	(0.020)	56.896***	(0.000)
Poland	25.66***	(0.000)	32.767***	(0.000)	36.405***	(0.000)
Romania	32.252***	(0.000)	25.747***	(0.000)	109.065***	(0.000)

Note: the table contains the results of the Breusch-Pagan LM test for the presence of an ARCH(1) component in the DGP; standard errors in parentheses, *** p< 0.01, ** p<0.05, * p<0.1.

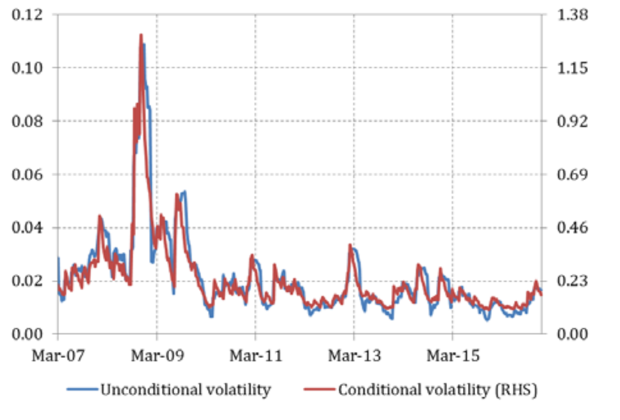
Table 4.A AR(1) GARCH (1,1) coefficients

	Stock market indices			Long-term bond yields			Exchange rate *vis-a-vis* the euro		
	ρ_1	α_1	β_1	ρ_1	α_1	β_1	ρ_1	α_1	β_1
Bulgaria	**0.376**	0.194	**0.794**	**0.129**	**0.308**	**0.663**	n.a.	n.a.	n.a.
	(0.048)* **	(0.158)	**(0.166)*** **	**(0.067)** **	**(0.118)*** **	**(0.083)*** **			
Croatia	**0.408**	**0.082**	**0.916**	**0.183**	**0.709**	0.368	**0.323**	**0.245**	**0.726**
	(0.049)* **	**(0.043)* **	**(0.041)*** **	**(0.084)** **	**(0.468)* **	(0.335)	**(0.051)*** **	**(0.058)*** **	**(0.045)*** **
Czech Republic	**0.281**	**0.283**	**0.661**	**0.493**	0.270	**0.737**	**0.195**	**0.177**	**0.759**
	(0.044)* **	**(0.146)** **	**(0.150)*** **	**(0.046)*** **	(0.219)	**(0.209)*** **	**(0.057)*** **	**(0.053)*** **	**(0.059)*** **
Hungary	**0.219**	**0.163**	**0.769**	**0.219**	**0.222**	**0.762**	**0.139**	**0.087**	**0.903**
	(0.049)* **	**(0.074)** **	**(0.084)*** **	**(0.055)*** **	**(0.062)*** **	**(0.061)*** **	**(0.047)*** **	**(0.036)** **	**(0.045)*** **
Poland	**0.244**	**0.174**	**0.799**	**0.204**	**0.136**	**0.783**	**0.175**	**0.127**	**0.846**
	(0.046)* **	**(0.059)*** **	**(0.056)*** **	**(0.047)*** **	**(0.048)*** **	**(0.068)*** **	**(0.046)*** **	**(0.044)*** **	**(0.058)*** **
Romania	**0.287**	**0.183**	**0.809**	0.093	**0.484**	**0.613**	**0.202**	**0.212**	**0.765**
	(0.055)* **	**(0.120)* **	**(0.112)*** **	(0.066)	**(0.240)** **	**(0.191)*** **	**(0.055)*** **	**(0.056)*** **	**(0.052)*** **

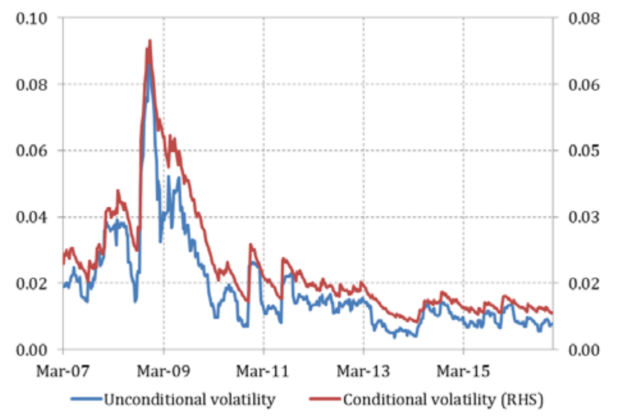
Note: standard errors in parentheses, *** p< 0.01, ** p<0.05, * p<0.1.

Chart 1.A Actual vs. fitted volatility in EU-6 stock market returns
(percentage points)

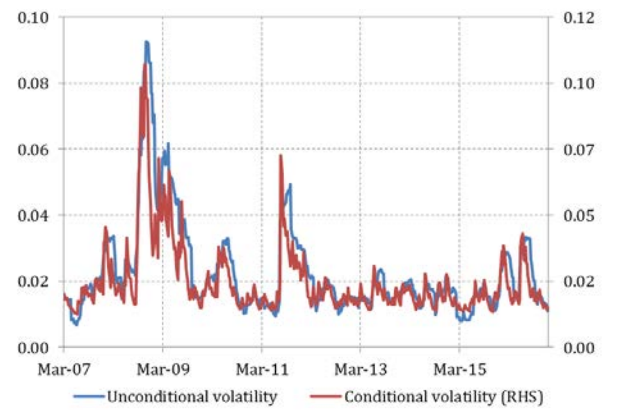
Bulgaria



Croatia



Czech Republic



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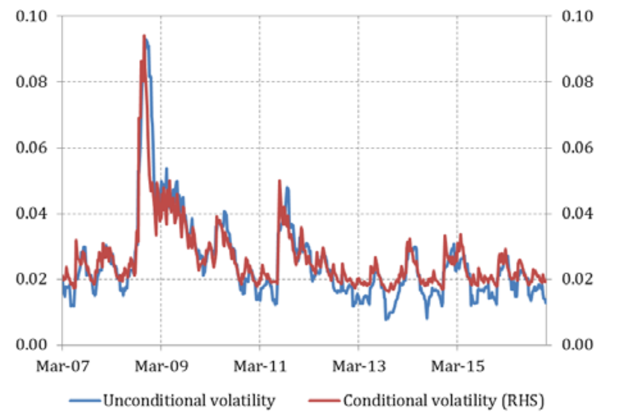

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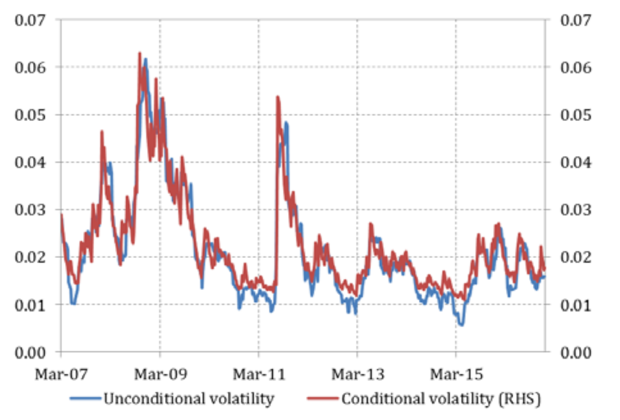

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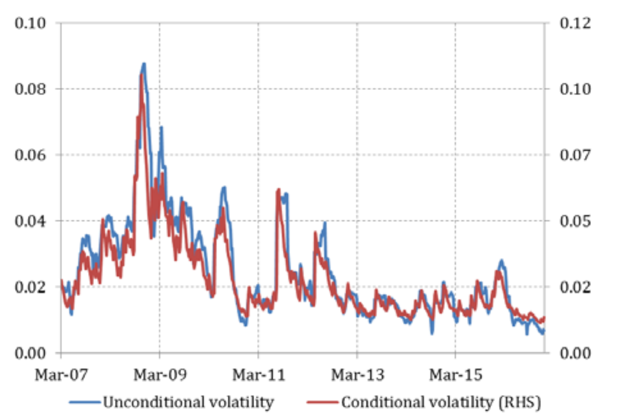
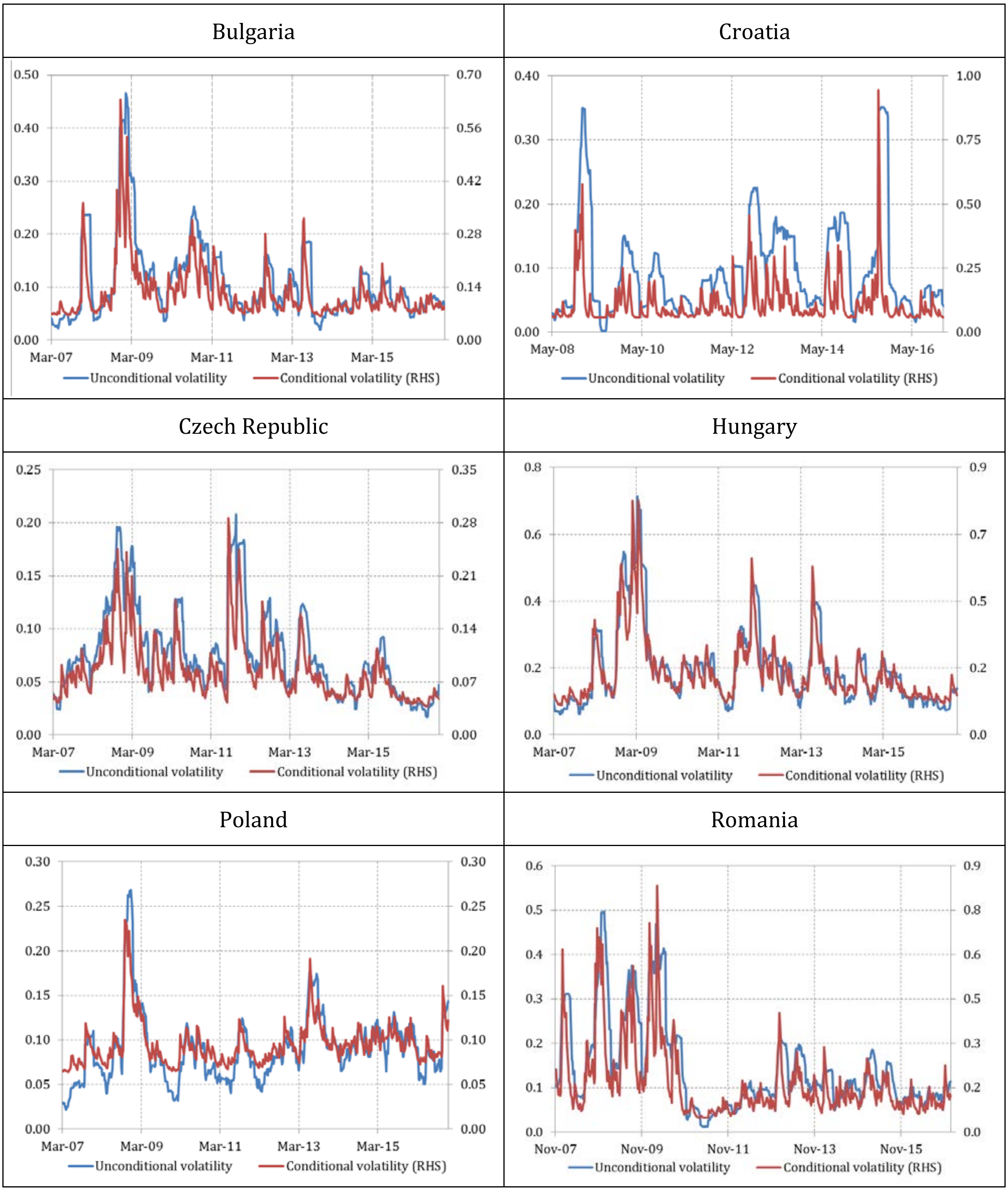


Note: unconditional volatility is calculated as the annualised 12-week rolling standard deviation of weekly asset price returns, while conditional volatility is calculated as the square root of the residuals from the AR(1)-GARCH(1,1) model.
Source: authors' calculations; Datastream.

Chart 2.A Actual vs. fitted volatility in EU-6 reference long-term yield changes
(percentage points)

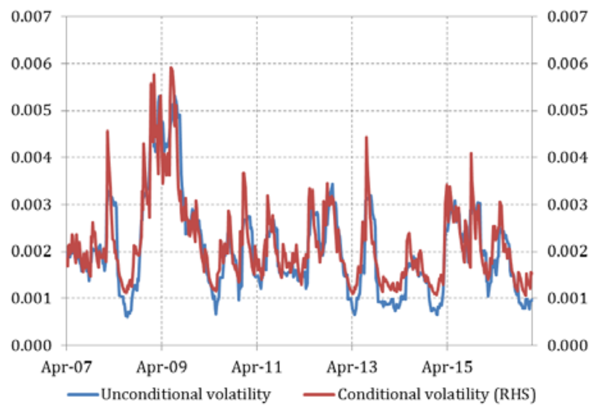


Note: unconditional volatility is calculated as the annualised 12-week rolling standard deviation of weekly asset price returns, while conditional volatility is calculated as the square root of the residuals from the AR(1)-GARCH(1,1) model.
Source: authors' calculations; Datastream.

Chart 3.A Actual vs. fitted volatility in foreign exchange returns
(percentage points)

Bulgaria

Croatia



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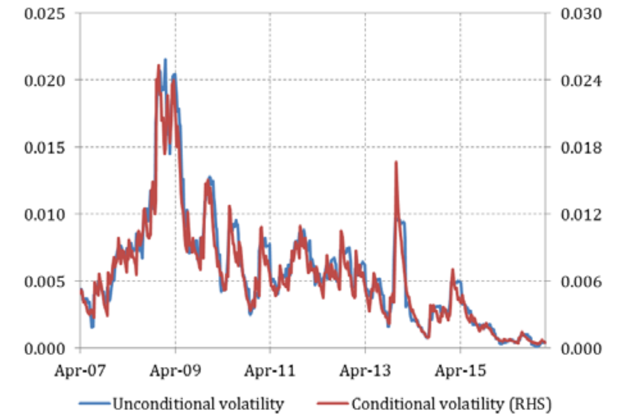

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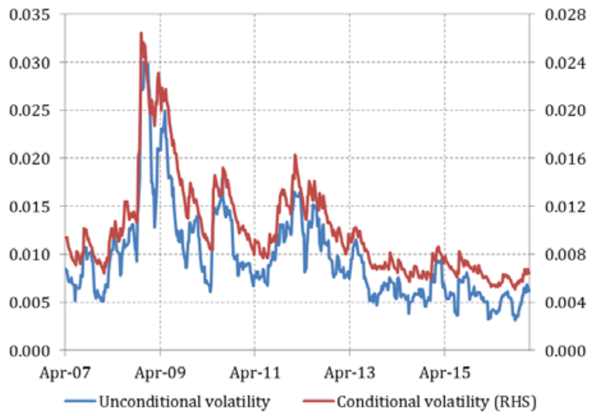

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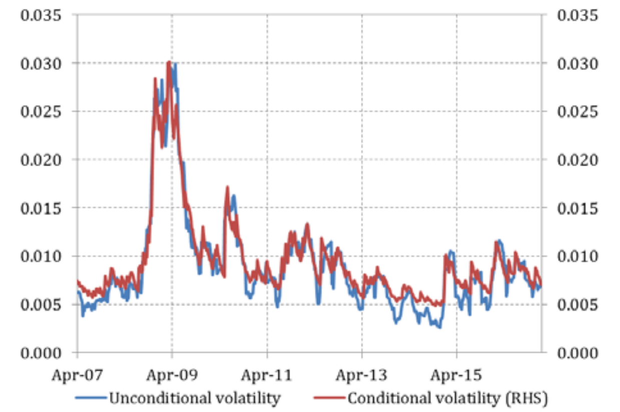

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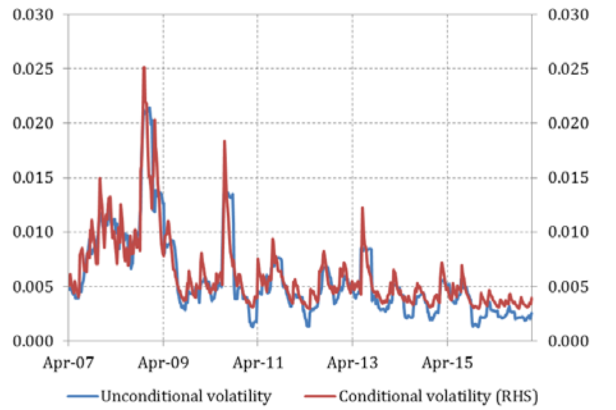

Note: unconditional volatility is calculated as the annualised 12-week rolling standard deviation of weekly asset price returns, while conditional volatility is calculated as the square root of the residuals from the AR(1) - GARCH(1,1) model; FX market regression for Bulgaria is not carried out because the country operates a currency-board arrangement *vis-à-vis* the euro.
Source: authors' calculations; Datastream.

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