Measuring the Effect of Unconventional Policies on Market Volatility

Demetrio Lacava[1] and Edoardo Otranto[2]

[1] University of Messina
dlacava@unime.it
[2] University of Messina
eotranto@unime.it

Abstract. As a response to the great recession, ECB resorted to unconventional monetary policies, i.e. central bank's balance sheet expansions. Our research aims to analyse the impact of unconventional monetary policy by ECB on stock market volatility in four Eurozone countries (France, Germany, Italy and Spain) within the Multiplicative Error Model framework. We propose a model to allow volatility to depend on unconventional monetary policy: in particular, we quantify the part of market volatility depending directly on unconventional policies by distinguishing between the announcement effect and the implementation effect, measured through a dummy variable and a proxy for securities held for monetary policy purpose, respectively. While we observe an increase in volatility on announcement days, we find a negative implementation effect, which causes a remarkable reduction in volatility in the long term. Moreover, we extend the analysis implementing a Markov Switching model to test the ECB ability to keep volatility in low and high regimes. In this case, it emerges how the average duration of the Quantitative Easing impact in keeping volatility in the low volatility regime is of about 15 days for France, Italy and Spain.

Keywords: Unconventional monetary policy · Financial market · Realized Volatility · Multilplicative Error Model · Markov Switching process.
JEL Codes: C32, C58, E44, E52, E58, G10

1 Introduction

During the great recession, with interest rate close to the zero lower bound, many central banks resorted to unconventional monetary policy measures in order to stimulate real economy. These policies consist of central bank's balance sheet expansion - generally through asset purchase programmes - which affects real economy by modifying inflation rate expectation during periods in which the so-called liquidity trap makes conventional policy, i.e. further cuts of interest rate, no longer effective.
Following other central banks such as Federal Reserve and Bank of England, the European Central Bank (ECB) established different unconventional monetary measures during the period 2009-2018.

Even though the main concern of these policies is the real economy, they have also unintended effects on financial markets that are largely studied by recent literature. Among these effects, it is crucial the positive influence that quantitative easing should have on market uncertainty. Thus, while most authors analyse the effect of unconventional policies on bond market (Boeckx, Dossche and Peersman, 2017; De Santis, 2016; Joyce, Lasaosa, Stevens and Tong, 2010; Krishnamurthy, Nagel and Vissing-Jorgensen, 2014), some others focus on stock market (Ciarlone and Colabella, 2016, 2018; Georgiadis and Grab, 2015) emphasizing the role played by the portfolio-rebalancing channel in transmitting monetary policy decisions (Breedon, Chadha and Waters,2012). Clearly, unconventional policies affect market returns and volatility since, by purchasing assets available in the market, the central bank reduces the amount of those assets incentivizing private investors to rebalance their portfolio, opting for a new preferred risk return configuration. In addition, notice how most of the unconventional policies by ECB were established to reduce market uncertainty, which is measured through the expected variance (Rompolis, 2017). Surprisingly, there exists a narrow literature concerning the impact of quantitative easing on volatility as key research objective (Apostolou and Beirne, 2017; Balatti, Brooks, Clements and Kappon, 2016; Kenourgios, Papadamou and Dimitriou,2015; Shogbuyi and Steeley, 2017), modelling volatility mainly through the GARCH family models (Engle, 1982; Bollerslev, 1986).

Despite the effectiveness of GARCH models, the new frontier in analysing volatility is represented by the Multiplicative Error Model, MEM (Engle, 2002; Engle and Gallo, 2006), in which volatility is the product of a time-varying factor (following a GARCH process) and a positive random variable ensuring positiveness without resorting to logs. Basing on MEM, Otranto (2015) proposes a new model to capture spillovers effects in financial markets, by decomposing the mean equation as the sum of two components, both evolving according to GARCH models. This model could be considered a general framework where inserting the effect of quantitative easing as an unobservable factor, providing its estimate and its weight on the level of volatility. In other terms, we further modify this model to allow volatility to depend on unconventional monetary policy. In particular, in our specification, the first equation composing the mean equation evolves as a GARCH model (capturing the pure volatility mechanism) while the second one follows an autoregressive process with exogenous variables, to capture both the announcement effect and the implementation effect of unconventional measures on volatility.

More precisely, our research aims to analyse the impact of unconventional monetary policy by ECB on stock market volatility in four Eurozone countries (France, Germany, Italy and Spain). We proxy for unconventional policies by using three different variables, relating with existing literature in using two of those, i.e. the balance sheet size growth (see for example Apostolou and Beirne, 2017; Voustinas and Werner, 2011) and the ratio between the securities purchased and total asset (D'amico, English, Lopez-Salido and Nelson, 2012; Voustinas and Werner, 2011).

In carrying out our analysis we employ a realized volatility measure based on high frequency data, which should remove endogeneity arising when monetary policy decisions coincide with a stock price reduction, as argued by Ghysels, Idier, Manganelli and Vergote (2014).
In addition, the volatility dynamics is characterized by several and frequent changes in regimes and frequent jumps, generally with a lower persistence with respect to the quiet periods; this fact could imply changes in the model parameters in unknown (a priori) time. We propose to extend the analysis implementing a Markov Switching model to test the ECB ability to keep volatility in low and high regimes.
The paper is organized as follow. Section 2 gives a general description of the unconventional programmes adopted by ECB together with an overview of the existing literature. Section 3 describes data, while section 4 analyses the high frequency methodology employed in our empirical analysis. Section 5 presents results. Finally, section 6 concludes with some remarks.

2 ECB's unconventional monetary policies and literature review

Starting from 2007 three different shocks - the decrease in price of commodity, the subprime mortgage crisis and the resulting stock market crash - hit the world economy, affecting the real economy with a widespread recession, especially in advanced countries. The crisis broke out in USA and reached Europe immediately, where a new wave of uncertainty - in particular because of fears of unsustainability of the sovereign debt of the so-called PIIGS country (Portugal, Ireland, Italy, Greece and Spain) - worsened the decrease in GDP observed in the first two years of the financial crisis. Moreover, over the last ten years, the EU economy, despite a deep reduction of interest rate (which was closer to zero and sometime even negative), was characterised by low inflation level. With the main purpose of avoiding the danger of deflation, ECB established many unconventional monetary policies - commonly known as quantitative easing (QE) - that aimed to bring inflation close to the target level of 2%.

The first experience in Europe with unconventional monetary policies date back 2008 when - few months later the collapse of Lehman Brothers which marks the beginning of the financial crisis - ECB launched the first 12-month Longer Term Refinancing Operations programme (LTRO) which aimed to contain the liquidity crisis and the consequent credit crunch the Eurozone experienced[3]. At the same time, with the main purpose to sustain a particular banks financing channel, ECB decided on the Covered Bond Purchase Programmes (CBPP1, CBPP2 in November 2011 and CBPP3 in October 2014) which reached a total amount of about €338 billion.

Different unconventional monetary policies were established by ECB to face the sovereign debt crisis caused mainly by an increase in government debt - deriving, among other factors, from the massive public action needed to bail out banks - together with low levels of GDP. These measures include the Security Market Programme (SMP), through which ECB bought more than €200 billion of government bond on the secondary market[4] and the Outright Money Transaction (OMT), which can be seen as the practical response to the famous "Whatever it takes" declaration by ECB's president Mario Draghi, who successfully attempted to reduce the increase in government bond yields caused by the emerging denomination risk.

Lastly, with the final goal to adjust the inflation level toward the target level of 2%, ECB launched the Extended Asset Purchase Program (EAPP), which

[3] It should be specified that generally LTROs have three-month maturity and fall within the conventional monetary policy (the Open Market Operations, in particular). Nevertheless, the extended maturity decided by the ECB (up to 3 years) allows us to consider this policy within the unconventional measures.

[4] SMP had a twofold objective of reducing the government bond spread and restoring the proper functioning of monetary policy transmission channel. It started in May 2010 with bond purchase of Greek, Ireland and Portugal and was extended in 2011 to consider also Italy and Spain government bonds.

refers to a series of unconventional measures such as the Assed Backed Securities (ABS), the CBPPs and the Corporate and Public Sector Purchase Program (CSPP and PSPP, respectively), through which ECB conducted securities purchasing up to € 80 billion for month[5].
Even though the unconventional monetary policies were designed to improve the output and inflation conditions when the interest rate reaches the zero lower bound - so that it is no possible to boost economy through further reduction of interest rate - they might have had unintended financial effects that have been largely studied in literature. Most authors analyse the impact of the unconventional monetary policies on both equity and bond returns and volatility.

Casiraghi, Gaiotti, Rodano and Secchi (2013) find that the SMP, which they proxy by considering the daily purchases, successfully reduced the Italian sovereign bond yields. Moreover, through an event study, they find a similar effect also considering the OMT announcement.
Many authors analyse the unconventional policies by means of event study, which allows analysing financial variables in a short window around the announcements, generally finding a reduction of bond yields around the announcement itself. In addition, for what concerns ECB's unconventional policies effect on bond market, it emerges how default risk and market segmentation were the dominant transmission channels for SMP and OMT (Krishnamurthy, Nagel and Vissing-Jorgensen, 2014) which, together with CBPPs and 3y-LTROs, diminished significantly borrowing cost for both banks and governments (Szczebowicz, 2012). The same framework was implemented also in study regarding FED and BoE unconventional monetary policies. Hattori, Schrimpf and Sushko (2013) find a reduction of uncertainty and risk aversion for both equity and bond market attributable to FED unconventional measures, with a greater effect associated to Forward Guidance than QE announcements. Differently, Joyce, Lasaosa, Stevens and Tong (2010) focus on the impact of BoE announcements on specific gilts yields within an interval of two days, finding a reduction between 70 bps and 150 bps for gilts yields and both investment and non-investment grade corporate bonds, mainly through the portfolio balancing channel (Breedon, Jagjit and Waters, 2012). Similarly, Steeley and Matyushkin (2015) focus on the individual gilts volatility finding evidence in favour of what they called Pre-announcement effect, i.e. a decrease in volatility in days preceding the BoE announcement. In addition, in the same study they implement a GARCH(1,1) model from which it derives a reduction in volatility from the QE programmes subsequent the QE1.

For what concern other markets, i.e. stock and exchange rate markets, Ciarlone and Colabella (2016) find how APPs by ECB improve significantly nominal exchange rate and stock market returns, in addition to 10-year govern-

[5] According to official ECB sources, it was of € 60 billion per month in the first year; between April 2016 and March 2017 it was incremented up to € 80 billion per month and then it came back to the previous level in the following 8 months; finally, in the last year of the programme the invested amount was decreased to € 30 billion per month from January to September 2018 and to € 15 billion per month between October and December 2018, when the programme ended.

ment bond yields, in CESEE economies. The same authors (Ciarlone Colabella, 2018), extend this analysis by means of a DCC-MGARCH. They proxy APPs through three different variables, and in particular the ECB's holding of securities for monetary policy purpose, finding out a sort of spillovers effect into these economies which decreases stock market and foreign exchange market volatility, while there is a no significant effect for what concerns bond market volatility. Contrary to Ciarlone and Colabella (2016), Georgiadis and Grab (2015) find EAPP announcement on 22, January 2015 boosts equity price in ASIA and USA, while the positive effects on sovereign bond yields remain confined to euro area. Finally, in line with Ciarlone and Colabella (2018), they find a depreciation of Euro that is lower if considered against advanced economies than against emerging market economies. According to Altavilla, Carboni and Motto (2015), the positive effect of this announcement on stock price and bond yields in Europe is mainly driven by signalling and risk premium channels. The latter, in particular, played a crucial role for the effectiveness of SMP, as shown by Eser and Schwaab (2016) through a panel model.

Despite event study approach has the great advantage to investigate the impact of specific events in a short window, it is widely recognized how results largely depend on the size of the window itself. Mainly for this reason, some authors prefer analysing unconventional monetary policy effects within the time series analysis framework, mainly using the Vector Autoregressive (VAR) approach. In this context, researches focus mainly on measuring simultaneously the financial and macroeconomic effects of unconventional policies. Altavilla, Giannone and Lenza (2014) find that the OMT announcement reduces significantly bond yields and volatility, with a positive effect on consumer price, in the meantime. Differently, Boeckx, Dossche and Peersman (2017), measuring unconventional monetary policy through the ECB total asset, find that the policies implemented in the period 2009-2014 stem financial risk by an improvement of lending conditions and a spread reduction between Eurozone and German government bonds. The same variable was used to investigate macroeconomic impact of APP finding an increase in output and price (Gambacorta, Hofmann and Peersman, 2012, in a multi-countries analysis; Lewis and Roth, 2017) and a reduction in both market uncertainty and risk aversion[6], measured through expected variance and variance risk premium, respectively (Rompolis, 2017).

Whereas the studies described so far focus mainly on the announcement effect, some authors analyse the impact of monetary policy shock. De Santis (2016) tests the impact of ECB's APP on GDP-weighted 10-year Eurozone bond, by estimating a panel error correction model. He states that since APP announcement on January 2015 was implicitly communicated to the market in October 2014, the impact of this announcement could be underestimated. For this reason, he constructs a new variable using the number of references to such a programme

[6] Similar results in Fratzscher, Lo Duca and Straub, 2014, whom proxy risk aversion through the VIX index and find a positive effect in Eurozone financial market in the period 2007-2012, i.e. increment in stock returns in core countries and reduction in peripheral countries' bond yields.

in news stories recorded on Bloomberg, finding an average reduction in GDP-weighted 10-year Eurozone bond yields by about 60 bps with higher benefits on peripheral countries. Haitsma, Unalmis and de Haan (2016) investigate the impact of monetary policy surprise in crisis and non-crisis periods - measured as the spread between German and Italian 10-year government bond (unconventional policies surprise) and the difference in three-month Euribor future spot rate (conventional policies surprise). Although they do not find a difference between conventional and unconventional policies, what emerges is a difference in the sign of these effects in crisis period with respect to pre-crisis period. While in the last case they are positive, in quiet periods the coefficient for conventional surprise is negative, meaning that an unexpected monetary easing leads an increase in stock returns. No difference between the effect of unconventional and conventional monetary policies emerges also in Rosa (2012), who constructs a surprise variable for measuring the surprise component of LSAP announcement by FED on stocks price, after controlling for target shock and news shock[7].
Rogers, Scotti and Wright (2014) provide a comparison between the effectiveness of asset purchase programmes of ECB, FED, BoE and BoJ. They define the monetary policies surprise as the intraday change in government bond yields around the announcement, finding a no significant effect on financial market only in Japan and a significant appreciation of Euro. Finally, Wright (2012) analyses the surprise effect through a VAR model, identifying the surprise by comparing variance-covariance matrix of VAR innovations on FOMC announcement days and over non-announcement days. He finds a significant effect on reducing yields for both long-term Treasury and corporate bond, even though this effect decays in few months.

Although financial market volatility, and in particular financial market stability, was investigate as a part of more extensive analysis in researches mentioned above, there are relatively few studies concerning financial stability as main objective. Of course, in most analysis financial market volatility is modelled within the ARCH framework. Shogbuyi and Steeley (2017), through a multivariate GARCH model, find a no significant effect of QE programmes by FED in reducing volatility in US market. Despite the increase in market volatility on specific days of QE operations by BoE, QE programmes successfully reduce volatility in UK market, on the one hand, and increase the covariance between UK and US market, on the other hand. A significant effect on US market volatility emerges in Tan and Kohli (2011) in which the VIX index falls significantly during the QE programme and increases when the programme itself ended. The GARCH model is also estimated in Apostolou and Beirne (2017) to investigate the volatility spillovers due to unconventional policies by FED and ECB - mea-

[7] The surprise variable takes value of 1 for LSAP announcement more restrictive than expected; 0 for no surprise and; -1 for LSAP announcement more expansionary than expected. Regarding target shock and news shock, they are defined as the change in current month federal fund future rate in a narrow window around FOMC announcement and the difference between what FMOC declares and what market expects, respectively.

sured as the change in their balance sheet size - in many emerging economies, in which they record positive volatility spillovers in bond market and negative ones for stock market.
In the same way, Converse (2015), using RV as a proxy for market uncertainty, finds out how FED QE3 programme increased bond market volatility during the first year of the programme, while equity volatility is lower during the same period.
Beetsma, de Jong, Giuliodori and Widijanto (2014) focus on Eurozone market finding a no significant impact of monetary policy common news, which becomes significant considering country specific news. Moreover, the considered news decrease correlation between distressed economies and Germany - regardless they are common or country specific - whereas they increase that between distressed countries.
Contrary to the previous literature, Kenourgios, Papadamou and Dimitriou (2015) find that QE announcement affects not only domestic currency but also other currencies. From the APARCH model they estimate, it emerges a positive transmission from EUR/USD and JPY/USD exchange rate to other currencies, while GBP is negatively related to volatility of EUR and JPY.
Finally, Balatti, Brooks, Clements and Kappon (2016) find a V shaped effect: initially the impact of US and UK QE programmes on volatility is positive and becomes negative after five months, in average. According to them, this indicates a spike in market volatility in days immediately following the announcement, while in the long run there would be a quiet period probably because of lower price movements deriving by the QE implementation.

3 The Data Set

In carrying out our time series analysis, we consider a database consisting of 2347 observations of annualized realized kernel volatility[8] of four market indexes (France, Germany, Italy and Spain) provided by the Oxford Man Institute[9], from June 1, 2009 to August 24, 2018. As shown by Barndorff-Nielsen, Hansen, Lunde and Shephard (2008), the realized kernel volatility is a robust estimator of the volatility, in particular with respect to microstructure noise of the markets.
We also allow our model to take into account the asymmetric effect, i.e. a higher volatility response to negative returns with respect to the positive ones[10].
To investigate the impact of unconventional monetary policy by ECB we consider two different variables, which refer to short term and long term effect on volatility, respectively. The short term effect is measured by means of a dummy variable taking value of 1 on days in which ECB releases communication regarding announcement, details and the end of unconventional programmes, and 0

[8] Data are, hence, expressed as percentage annualized RV. That is, $\sqrt{RV * 252} * 100$.
[9] The latest version is available at `https://realized.oxford-man.ox.ac.uk/data/download`.
[10] We obtain returns as the log difference of market index closing price between two consecutive days (data are available at: `https://www.investing.com/`).

otherwise[11]. To proxy for the long-run effect we construct three different variables: i) the change in ECB's balance sheet size (Apostolou and Beirne, 2017; Voustinas and Werner, 2011); ii) the amount of securities held by ECB as a fraction of total asset, named UMP/TA (similarly to D'amico, English, Lopez-Salido and Nelson, 2012; Voustinas and Werner, 2011) and; iii) the amount of securities held for unconventional policies with respect to that held for conventional measures, UMP/CMP. More precisely, since what matters for the effectiveness of these policies is the balance sheet composition, rather than its size (Curdia e Woodford, 2011), the last proxy should measure the effect on market volatility of the unconventional policies weight - relative to the conventional policies weight - in ECB balance sheet. We obtain daily data on securities held for monetary policy purpose from ECB website[12] and Datastream.
Looking at the descriptive statistics (table 1) one can note a similarity between the France and Germany RV series, which have a lower mean value than that of Italy and Spain, as expected. In fact, the latter countries, during the sample period, experience a deeper recession, which contributes to create uncertainty among investors with a direct impact on financial market.
Secondly, the high difference between the minimum and the maximum value in all the series gives us a crucial justification for estimating a model with changes in regimes.

Table 1. Descriptive statistics for CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. Sample period: June 1, 2009 to August 24, 2018. Observation: 2347.

	France	**Germany**	**Italy**	**Spain**
Mean	14.12	14.29	15.97	17.31
Median	12.48	12.78	14.29	15.34
Min	2.28	2.14	1.58	3.5
Max	79.65	88.44	77.72	148.61
St.Dev.	7.69	7.51	7.94	9.27
Skewness	2.16	2.17	2.04	3.1
Kurtosis	12.08	12.94	10.51	27.34

This is also shown by figure 1, which plots the annualized kernel volatility series for the considered countries. In all the series it is quite clear how volatility clustering affects all the series: one can notice, indeed, how volatility is high, for example, between August and November 2011, whereas it stays at low level for a long period between July 2012 and the end of 2014. In the same figure,

[11] We obtain information relative to monetary policy decisions, needed to construct our dummy variable, from the ECB website: `https://www.ecb.europa.eu/press/pr/activities/mopo/html/index.en.html`.
[12] Available at: `https://www.ecb.europa.eu/stats/policy\_and\_exchange\_rates/minimum\_reserves/html/index.en.html`.

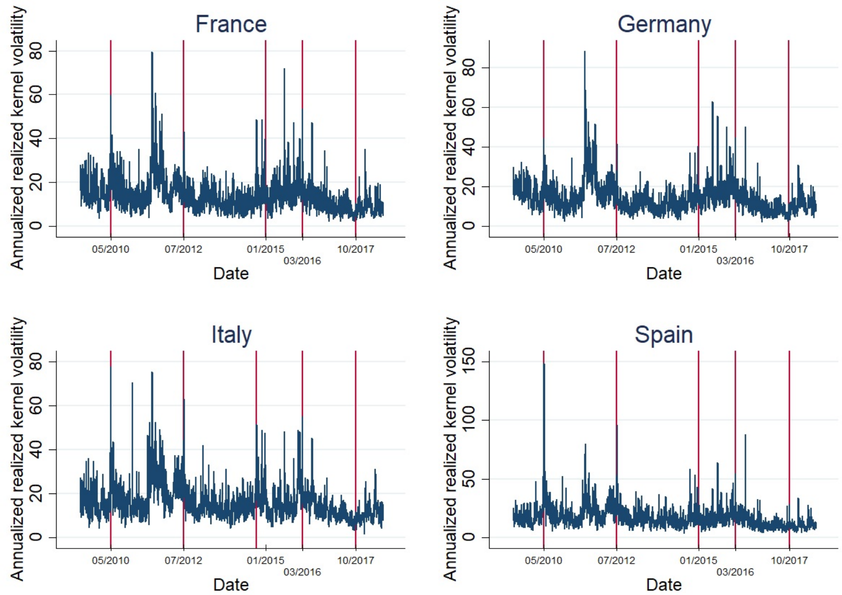

Fig. 1. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. Sample period: June 1, 2009 to August 24, 2018. Observation: 2347.

we highlight some important dates (red lines) which give us a first idea on how unconventional policies affect market volatility. More in detail:

– SMP announcement on May 10, 2010. It was designed to manage the spread increase by purchasing government bonds. Initially just bonds of Greek, Ireland and Portugal came into the purchase programme, which in 2011 was extended also to Italy and Spain government bonds: one can notice, indeed, the significant reduction in volatility observed in August 2011, when Italy and Spain government bond entered in the programme.
– "Whatever it takes" declaration by Mario Draghi on July 26, 2012, which served to reassure investors regarding the emerging denomination risk.
– EAPP announcement on January 22, 2015. It was established mainly to improve monetary policy transmission mechanisms, to contrast credit crunch so as to create conditions for banks to increase financing for the real economy and, finally, contributing to one of the main ECB's objective, that is to adjust the inflation rate toward to the target level of 2%.
– March 10, 2016. The purchased amount of securities within the EAPP was incremented to €80 billion per month. What emerges is an effect caused also by the amount purchased by ECB.
– October 26, 2017. Volatility increases after the announcement through which ECB communicated the cut in the monthly purchases, which reduced to €15

billion.

A simple visual inspection shows the decrease of volatility in correspondence of the previous events. Our purpose is to quantify the effect of these events on the level of volatility and to evaluate their duration.

4 The models

4.1 AMEM

Let us call RV_t the realized volatility of a certain asset (index) at time t. Since volatility is the evolution of a non-negative process, Engle (2002) and Engle and Gallo (2006) propose to model it as the product of a time-varying factor μ_t, representing the conditional expectation of the volatility and following a GARCH type dynamics, and a positive random variable:

$$\begin{array}{l} RV_t = \mu_t \epsilon_t, \;\; \epsilon_t | \Psi_{t-1} \sim Gamma(\vartheta, \frac{1}{\vartheta}) \\ \mu_t = \omega + \alpha RV_{t-1} + \beta \mu_{t-1} + \gamma D_{t-1} x_{t-1} \end{array} \tag{1}$$

where Ψ_t is the information set available at time t, and D_t a dummy variable taking value 1 if the return of the asset (index) at time t is negative, 0 otherwise. In this model, called Asymmetric Multiplicative Error model (AMEM), the usual constraints for positiveness and stationarity are imposed: $\omega > 0$, $\alpha \geq 0$, $\beta \geq 0, \gamma \geq 0$ and $(\omega + \alpha + \beta + \frac{\gamma}{2}) < 1$. Finally, as for the GARCH model, this causes the unconditional mean equal to

$$\mu = \frac{\omega}{1-\alpha-\beta-\frac{\gamma}{2}}$$

Considering the conditional distribution of RV_t, it is simple, given the assumption of a Gamma distribution depending only on a parameter, to verify that:

$$E\left(RV_t|\Psi_{t-1}\right) = \mu_t \qquad Var\left(RV_t|\Psi_{t-1}\right) = \mu_t^2/\vartheta.$$

This last property shows that the AMEM possesses a very flexible structure, implying not only a time–varying conditional mean, but also a time–varying conditional variance (volatility of volatility), with the possibility to capture possible clustering in residuals.

4.2 Factor AMEM

Starting from this specification, we develop it to insert the effect of the QE as a latent factor, which affects the dynamics of the volatility. Our specification is similar to the model developed by Otranto (2015) to capture the spillovers effects in financial markets, being based on the decomposition of the volatility level in the sum of two unknown factors, representing, respectively, the ”proper” volatility of the market and the effect of the unconventional policies. The great

advantage of this representation consists in the possibility to quantify the last one and to verify its effect on the global volatility of the market.
More in detail, the model we propose (call it Factor AMEM–FAMEM) consists of four equations:

$$
\begin{aligned}
&RV_t = \mu_t \epsilon_t, \;\; \epsilon_t | \Psi_{t-1} \sim Gamma(\vartheta, \tfrac{1}{\vartheta}) \\
&\mu_t = \varsigma_t + \xi_t \\
&\varsigma_t = \omega + \alpha RV_{t-1} + \beta \varsigma_{t-j} + \gamma D_{t-1} RV_{t-1} \\
&\xi_t = \delta x_t + \varphi \Delta_t + \phi \xi_{t-1}
\end{aligned}
\tag{2}
$$

where ς_t represents the proper volatility of the market, due to its intrinsic dynamics, which evolves as the second equation in (1); ξ_t represents the effect due to the unconventional policies and follows an AR(1) process with exogenous variables x_t and Δ_t. Δ_t is a dummy variable, taking value 1 in day characterized by the communication of unconventional policies news by ECB, 0 otherwise: it represents the effect of the announcement of the Central Bank. The other variable, x_t, represents, in turn, the growth of ECB balance sheet size, the ratio between the amount employed in unconventional polices and total asset and, finally, the ratio between the amount invested for unconventional policies purposes and the amount invested for conventional policies.

It is important to underline that ξ_t is an unobservable signal, with a proper dynamics, which represents the part of the conditional mean of realized volatility due to the unconventional policies. After estimation we will obtain an inference on this signal, so it will be possible to quantify and plot the effect of the unconventional ECB actions on the volatility RV_t.

The estimation procedure is based on the quasi maximum likelihood estimator, so that the estimators of the unknown coefficients in (2) are consistent and asymptotically normal, as shown by Engle (2002) for the MEM case. As discussed by Engle and Gallo (2006), if the Gamma distribution is appropriate for ϵ_t, this procedure gives us consistent and efficient estimators (given the Quasi-Maximum likelihood interpretation); if θ is unknown (as usual), robust standard errors will shield against the shape of the Gamma distribution.

4.3 Markov-Switching Factor AMEM

As shown by figure 1, the volatility dynamics is characterized by several and frequent changes in regimes and frequent jumps, which could imply changes in the model parameters in unknown (a priori) time. We propose to extend the analysis implementing a Markov Switching model (Hamilton,1990), which makes us capable to give a complete answer to the crucial question regarding the link between the amount of purchased securities by central bank and the effectiveness of these extraordinary measure and, more important, how long the effect of these policies lasts. In particular, basing on the idea that the presence of different phases of volatility correspond to different regimes in the MEM process generating data (Gallo and Otranto, 2015), we investigate whether the unconventional policies contributes in switching volatility from a high to a low regime.

We therefore consider a Markov Switching (MS) model with two regimes (high and low volatility regimes, label them with 1 and 0 respectively). Extending the model of Gallo and Otranto (2015), the general specification of the MS–FAMEM is:

$$\begin{array}{l} RV_t = \mu_{t,s_t}\epsilon_t, \;\; \epsilon_t|\Psi_{t-1} \sim Gamma(\vartheta_{s_t}, \frac{1}{\vartheta_{s_t}}) \\ \mu_{t,s_t} = \varsigma_{t,s_t} + \xi_t \\ \varsigma_{t,s_t} = \omega_0 + \omega_1 s_t + \alpha_{s_t} RV_{t-1} + \beta_{s_t}\varsigma_{t-1,s_{t-1}} + \gamma_{s_t} D_{t-1}x_{t-1} \\ \xi_t = \delta x_t + \varphi \Delta_t + \phi \xi_{t-1} \end{array} \tag{3}$$

where $s_t = 0, 1$ is a discrete dichotomic latent variable representing the regime at time t. All the coefficients of the proper volatility (third equation) and the parameter of the Gamma distribution can vary according to the regime at time t; in the low volatility regime (regime 0) the constant of the proper volatility is ω_0, whereas in the regime 1 of high volatility it is $\omega_0 + \omega_1 s_t$ with $\omega_1 \geq 0$. Finally, the changes in regime are driven by a Markov chain, represented by:

$$Pr(s_t = js_{t-1} = i, s_{t-2} \ldots) = Pr(s_t = js_{t-1} = i) = p_{ij}$$

In our application, we consider two alternatives of model (3): 1) a model where only the constant in the third equation and the Gamma parameter can switch; 2) a model where all parameters in ς_t equation and the Gamma coefficient switch, as in the general form (3).

As usual, we estimate the MS–FAMEM by means of the Hamilton filter and smoother (Hamilton, 1994) together with the solution proposed by Kim (1994) to solve the problem arising due to the dependence of μ_{t,s_t}on s_{t-1}, which causes the need to track all the possible paths of the regime between the first and the last observation. In particular, after each step of Hamilton filter, we collapse the 4 possible values of μ_t into 2 values, through a weighted average at time t-1:

$$\mu_{t,s_t} = \frac{\sum_{i=1}^{n} Pr[s_{t-1}=i, s_t=j|\Psi_t]\mu_{t,s_t-1,s_t}}{Pr[s_t=j|\Psi_t]}$$

with μ_{t,s_t-1,s_t} the estimate of the unknown variable weighted with the filtered probabilities obtained by the Hamilton filter.

5 Estimation results

In this section, we present the estimation results by dividing results referring to the FAMEM, from those deriving from the MS models.

The estimation of the AMEM, which we use as guideline, gives us similar results for all countries, as shown in table 2. All models present coefficients highly significant (at 1% level) and a high level of persistence, calculated as $(\alpha + \beta + \gamma/2)$, ranging between 0.91 (Italy) and 0.94 (France). The impact of the news, represented by the coefficients α and γ, seems strong (around 0.2 with an increase

around 0.1 in presence of negative news). In the same table we show the Ljung-Box statistics for lags 1, 5 and 10, showing as the AMEM is able to capture the autoregressive structure of the volatilities of the models (in fact we do not reject the null of uncorrelation at 1% significance, excluding Germany at the higher lags).
For what concerns the Factor model, we present results just for two proxies, i.e. the amount of securities invested for unconventional monetary policies over the amount invested for conventional ones (UMP/CMP), and for the amount invested in unconventional policies over total asset (UMP/TA), for a comparison purpose.
Crucially, even we do not report results relative to balance sheet size growth, which are available upon request, we find it is statistically significant in 2 out of 4 countries only when changes in regime are not considered, supporting the idea that what matter is the balance sheet composition, not the size (Curdia and Woodford, 2011).

5.1 FAMEM Results

In table 3 the estimation results for the FAMEMs are shown. It is interesting to underline as the coefficient β, in general, changes slowly with respect to the AMEM case, whereas α decreases and γ increases; in particular α decreases more than 11% for France and Spain. Considering the significance of the coefficients representing the short term and long term effect of the unconventional policies, a first result is that QE has a significant effect on the volatility, in particular during the quiet periods.
According to other researches in literature (see for example Bomfim, 2003; Chan and Gray, 2018 and; Shogbuyi and Steeley, 2017) the coefficient φ of the dummy variable has a positive sign, meaning that, in days in which there is an unconventional policy communication, there is an immediate reaction in the market with a clear increase of volatility between 2.4 points for the strongest market (Germany) and 3.2 points for Italy, which is the most sensible market to this kind of policy.
As expected, the proxy enters in the model with a negative sign for all countries, meaning that unconventional policies successfully reduce stock market volatility in the longer run. Here again, the effect is greater for Italy, but in general the difference between core and peripheral countries is less evident than expected. A unit increase of the ratio between amount employed for unconventional policies and ECB's total asset leads to a reduction in realized volatility of 2.1 points for Germany, France and Spain and 2.5 points for Italy.
In statistical terms, this model specification improves the performance in terms of Ljung-Box statistics for Germany, so that all the models seem to capture the autoregressive structure of the volatility of the four markets.
The signal representing the effect of unconventional policy seems not to have an autoregressive dynamics, excluding Spain, which shows the only significant AR coefficient.

Table 2. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the AMEM. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

a)

	France	**Germany**	**Italy**	**Spain**
ω	0.872 ***	1.006 ***	1.323 ***	1.198 ***
	(0.104)	(0.002)	(0.128)	(0.172)
α	0.169 ***	0.199 ***	0.258 ***	0.222 ***
	(0.022)	(0.01)	(0.03)	(0.033)
β	0.71 ***	0.683 ***	0.608 ***	0.664 ***
	(0.029)	(0.009)	(0.033)	(0.039)
γ	0.113 ***	0.09 ***	0.094 ***	0.088 ***
	(0.009)	(0.009)	(0.019)	(0.014)
ϑ	7.712 ***	9.37 ***	10.742 ***	9.068 ***
	(0.245)	(0.31)	(0.471)	(0.341)
b)				
Ljung-Box lag 1	1.997	1.919	0.599	0.679 **
	(0.158)	(0.166)	(0.439)	(0.017)
Ljung-Box lag 5	8.799	11.929 **	3.650	12.635 **
	(0.117)	(0.036)	(0.601)	(0.027)
Ljung-Box lag 10	16.535 *	28.119 ***	13.019	16.96 *
	(0.085)	(0.002)	(0.223)	(0.075)

Similar results are obtained when we estimate the model by using the other proxy, UMP/CMP. The sign and the significance of the dummy variable Δ_t do not change; here too, the lowest parameter is recorded for Germany (2.4) and the higher for Italy (3.2).
Even in this case, the proxy enters in the model with a negative sign but with a remarkably lower magnitude. The highest effect, again for Italy, is now about -0.99, meaning that the increase of securities held for unconventional policies purpose, relative to that held for conventional purpose, leads to a reduction in realized volatility of about 1 point. This long run effect can be seen also in figure 2, which plots the evolution of the two part of volatility (ς, the blue line, and ξ, red line). This effect is more evident starting from October 2014 - when the ECB for the first time communicated to the market it would purchase also private sector bond (as well as government bond) - coming in the form of change in the slope of ξ equation (red line), which lasts for the entire period of the programme. This is, perhaps, the most interesting result since it should mean that the quantity of securities held for monetary purpose, related to both total asset and securities held for conventional policies purpose, is actually crucial for the effectiveness of these unconventional policies. In addition, in April 2017 it can be observed an increase in volatility, which is probably due to the reduction in amount of securities purchased by ECB falling down to €60 billion from the previous level of €80 billion.
Comparison between models (table 5) is based on the information criteria (AIC and BIC) and the loss functions for evaluating the forecasting power of the models (MSE and MAE). For 3 out of 4 countries, in all cases the preferred model is that in which unconventional policies are measured through UMP/CMP, while Germany is the only market in which the preferred model is that in which balance sheet size growth is used as a proxy. In this specific case, our model works better only in terms of MAE function.

Table 3. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the FAMEM with Proxy UMP/TA. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

a)

	France	**Germany**	**Italy**	**Spain**
ω	1.113 ***	1.141 ***	1.744 ***	1.638 ***
	(0.166)	(0.115)	(0.164)	(0.174)
α	0.150 ***	0.187 ***	0.248 ***	0.198 ***
	(0.022)	(0.02)	(0.021)	(0.025)
β	0.72 ***	0.693 ***	0.605 ***	0.671 ***
	(0.031)	(0.026)	(0.027)	(0.031)
γ	0.116 ***	0.094 ***	0.095 ***	0.091 ***
	(0.013)	(0.01)	(0.008)	(0.011)
δ	-2.112 ***	-2.058 **	-2.536 ***	-2.111 ***
	(0.583)	(0.286)	(0.362)	(0.5)
φ	2.872 ***	2.404 ***	3.191 ***	2.89 ***
	(0.658)	(0.594)	(0.718)	(0.768)
ϕ	0.179	0.051	0.068	0.347 **
	(0.157)	(0.082)	(0.065)	(0.134)
ϑ	7.946 **	9.625 ***)	11.149 ***	9.359 ***
	(0.259)	(0.332)	(0.482)	(0.370)

b)

	France	**Germany**	**Italy**	**Spain**
Ljung-Box lag 1	2.035	1.52	0.343	6.043 **
	(0.154)	(0.218)	(0.558)	(0.014)
Ljung-Box lag 5	7.242	8.744	2.081	13.591 **
	(0.203)	(0.12)	(0.839)	(0.018)
Ljung-Box lag 10	12.052	20.759 **	10.617	16.65 *
	(0.282)	(0.023)	(0.388)	(0.082)

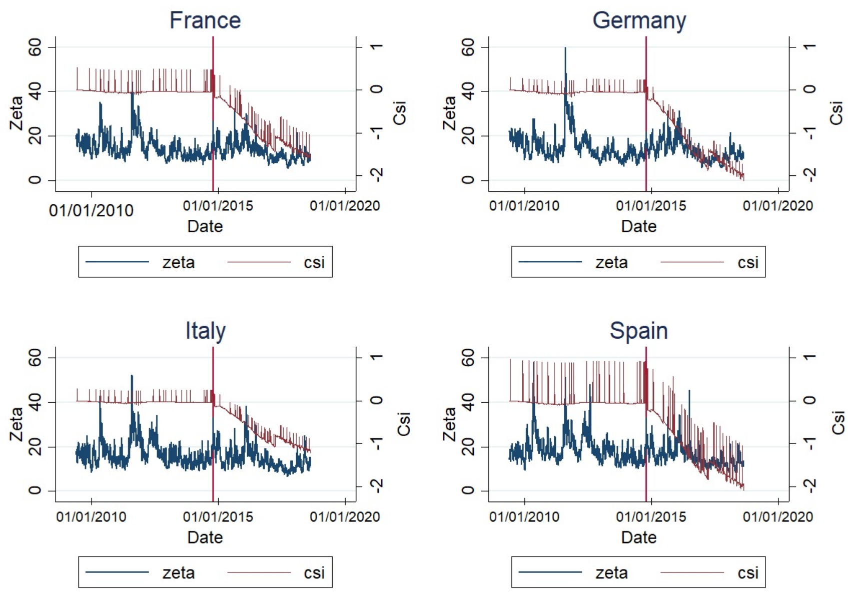

Fig. 2. CAC40, DAX30, FTSE MIB and IBEX35 zeta and csi functions obtained from FAMEM. Proxy: UMP/CMP. Sample period: June 1, 2009 to August 24, 2018. Observation: 2347.

Table 4. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the FAMEM with Proxy UMP/CMP. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

Panel a)

	France	**Germany**	**Italy**	**Spain**
ω	1.146 ***	1.153 ***	1.746 ***	1.686 ***
	(0.208)	(0.148)	(0.162)	(0.174)
α	0.149 ***	0.186 ***	0.249 ***	0.197 ***
	(0.026)	(0.022)	(0.021)	(0.023)
β	0.717 ***	0.692 ***	0.601 ***	0.667 ***
	(0.038)	(0.03)	(0.028)	(0.029)
γ	0.117 ***	0.095 ***	0.094 ***	0.092 ***
	(0.012)	(0.011)	(0.009)	(0.009)
δ	-0.857 ***	-0.83 ***	-0.99 ***	-0.837 ***
	(0.166)	(0.228)	(0.205)	(0.191)
φ	2.868 ***	2.4 ***	3.176 ***	2.856 ***
	(0.671)	(0.6)	(0.713)	(0.78)
ϕ	0.192 *	0.059	0.068	0.37 **
	(0.1)	(0.187)	(0.154)	(0.123)
ϑ	7.966 ***	9.641 ***	11.151 ***	9.383 ***
	(0.26)	(0.332)	(0.481)	(0.3721

Panel b)

	France	**Germany**	**Italy**	**Spain**
Ljung-Box lag 1	1.81	1.36	0.302	5.691 **
	(0.178)	(0.243)	(0.583)	(0.017)
Ljung-Box lag 5	7.191	8.631	2.147	13.107 **
	(0.207)	(0.125)	(0.828)	(0.022)
Ljung-Box lag 10	11.958	20.598 **	10.914	17.193
	(0.288)	(0.024)	(0.364)	(0.102)

Table 5. Log-likelihood, AIC, BIC, MSE, MAE for AMEM and FAMEM estimated with the three proxies (in bold the best value for each function).

France	**AMEM**	**Factor Model UMP/CMP**	**Factor Model UMP/TA**	**Factor Model TA growth**
Log-likelihood	-6905.064	**-6865.345**	-6868.473	-6891.581
AIC	5.888	**5.857**	5.86	5.882
BIC	5.901	**5.877**	5.879	5.902
MSE	31.44	**30.89**	30.924	31.171
MAE	3.953	**3.913**	3.918	3.936

Germany	**AMEM**	**Factor Model UMP/CMP**	**Factor Model UMP/TA**	**Factor Model TA growth**
Log-likelihood	-6714.296	-6679.717	-6681.703	**-6670.345**
AIC	5.726	5.699	5.701	**5.693**
BIC	5.738	5.719	5.72	**5.713**
MSE	25.224	24.861	24.889	**24.751**
MAE	3.484	**3.455**	3.457	3.461

Italy	**AMEM**	**Factor Model UMP/CMP**	**Factor Model UMP/TA**	**Factor Model TA growth**
Log-likelihood	-6843.959	**-6798.794**	-6798.972	-6827.194
AIC	5.836	**5.8**	5.801	5.827
BIC	5.849	**5.82**	5.82	5.847
MSE	30.398	**29.873**	29.878	30.063
MAE	3.753	**3.709**	3.71	3.732

Spain	**AMEM**	**Factor Model UMP/CMP**	**Factor Model UMP/TA**	**Factor Model TA growth**
Log-likelihood	-7217.498	**-7176.005**	-7179.067	-7208.884
AIC	6.155	**6.122**	6.124	6.152
BIC	6.167	**6.141**	6.144	6.172
MSE	46.009	**45.004**	45.028	45.507
MAE	4.494	**4.440**	4.449	4.486

5.2 MS–FAMEM Results

We estimate the MS–FAMEM with the main purpose to assess the ECB ability to keep volatility in low regime, computing the average duration of unconventional policies effect on realized volatility. Within the MS framework, we distinguish between low and high volatility regimes and measure the average duration of the calming effect as the probability to stay in the low volatility regime, computed as $\frac{1}{1-p_{ii}}$ $(i = 0, 1)$.

We focus on two different specifications of the MS–FAMEM, which differ in the switching parameters: in the first specification, only the constant is subject to changes of regimes(see third equation in (3)); in the second one we allow for switching in all the parameters in the ς equation. Again, we choose the best model basing on information criteria and loss functions for forecasting evaluation.

Starting from the first specification, for France and Germany it results a no significant constant in one of the two regimes, when we consider UMP/TA as a proxy (table 6). The proxy and the dummy variable enter in the model with the expected sign and they are highly significant in all cases. As expected, the lowest effect, both in the short run and long run, is for Germany, while the highest is observed for Italy, in the short run (dummy parameter of about 3.116) and for Spain in the long run (-1.761). Nothing changes in parameters sign and significance when we estimate the model by using UMP/CMP as a proxy (table 7), with the constant parameters that are now significant in both regimes also in France and Germany. Interesting, this proxy seems to have a higher long run effect in core countries than in peripheral ones.

Important information is contained in the probability coefficients. It emerges a higher probability in remaining in the low volatility regime (regime 0) for France (0.905), Italy (0.922) and Spain (0.886) when we use UMP/TA as a proxy (tables 6). Moreover, in these countries the probability of moving from high to low volatility regime is higher than the probability of moving from low to high volatility regime (computed as $1 - p_{11}$ and $1 - p_{00}$, respectively). Probabilities remain almost unchanged in using the second proxy (table 7), leading to an average duration of low volatility regime of about 11 days for France, 13 days for Italy and 9 days for Spain. The average duration is perhaps lower than one might expect but it is plausible if compared with the average duration of high volatility regime, which in these countries is about 1 day, meaning that the high volatility regime is represented, basically, by volatilities spikes. A different case is that of Germany where there is also a higher probability to stay in the high volatility regime. Here, we estimate an average duration of 250 days and 200 days for low and high volatility regime, respectively. Clearly, this result is in line with the higher long run effect (-1.021) estimated for this market, if compared with the other markets, when we proxy unconventional policies through UMP/CMP variable (table 7).

Table 6. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the MS–FAMEM–1^{st} specification with Proxy UMP/TA. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

a)	**France**	**Germany**	**Italy**	**Spain**
ω_0	0.537	1.31 **	0.949 ***	0.924 ***
	(0.404)	(0.665)	(0.043)	(0.086)
ω_1	2.588 ***	0.906	3.178 ***	2.806 ***
	(0.493)	(0.819)	(0.747)	(0.555)
α	0.109 ***	0.145 ***	0.218 ***	0.147 ***
	(0.038)	(0.055)	(0.022)	(0.021)
β	0.786 ***	0.688 ***	0.669 ***	0.742 ***
	(0.048)	(0.048)	(0.021)	(0.023)
γ	0.107 ***	0.106 *	0.082 ***	0.089 ***
	(0.011)	(0.058)	(0.008)	(0.009)
δ	-1.746 ***	-1.505 **	-1.52 ***	-1.761 ***
	(0.405)	(0.664)	(0.344)	(0.680)
φ	2.78 ***	2.49 ***	3.116 ***	2.545 ***
	(0.63)	(0.843)	(0.613)	(0.656)
ϕ	0.173 *	0.072	0.088	0.371
	(0.101)	(0.222)	(0.108)	(0.25)
p_{00}	0.905 ***	0.995 ***	0.922 ***	0.886 ***
	(0.154)	(0.01)	(0.032)	(0.047)
p_{11}	0.041	0.994 ***	0.057	0.057
	(0.08)	(0.013)	(0.08)	(0.07)
ϑ_0	9.389 ***	9.841 ***	14.735 ***	12.343 ***
	(0.915)	(0.484)	(0.778)	(0.67)
ϑ_1	4.424 *	11.047 ***	3.921 ***	3.955 ***
	(2.292)	(0.91)	(1.028)	(0.752)
b)				
Ljung-Box lag 1	3.848 **	0.953	1.245	14.303 ***
	(0.05)	(0.329)	(0.264)	(0.0001)
Ljung-Box lag 5	7.974	7.357	3.142	20.531 ***
	(0.158)	(0.195)	(0.678)	(0.0009)
Ljung-Box lag 10	10.032	16.437 *	9.516	23.394 ***
	(0.438)	(0.088)	(0.484)	(0.009)

Table 7. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the MS–FAMEM–1^{st} specification with Proxy UMP/CMP. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

a)	**France**	**Germany**	**Italy**	**Spain**
ω_0	0.584 **	1.408 ***	0.952 ***	0.982 ***
	(0.239)	(0.174)	(0.056)	(0.022)
ω_1	2.591 ***	0.815 ***	3.181 ***	2.774 ***
	(0.678)	(0.122)	(1.023)	(0.574)
α	0.11 ***	0.147 ***	0.219 ***	0.148 ***
	(0.024)	(0.017)	(0.022)	(0.018)
β	0.782 ***	0.679 ***	0.666 ***	0.737 ***
	(0.032)	(0.027)	(0.02)	(0.02)
γ	0.108 ***	0.107 ***	0.082 ***	0.09 ***
	(0.011)	(0.01)	(0.008)	(0.008)
δ	-0.728 ***	-1.021 ***	-0.606 ***	-0.708 ***
	(0.338)	(0.234)	(0.129)	(0.265)
φ	2.776 ***	2.507 ***	3.114 ***	2.516 ***
	(0.857)	(0.654)	(0.615)	(0.871)
ϕ	0.185	0.115	0.09	0.383 *
	(0.442)	(0.204)	(0.086)	(0.219)
p_{00}	0.912 ***	0.995 ***	0.921 ***	0.893 ***
	(0.91)	(0.003)	(0.035)	(0.042)
p_{11}	0.038	0.996 ***	0.058	0.06
	(0.105)	(0.003)	(0.157)	(0.07)
ϑ_0	9.364 ***	9.784 ***	14.77 ***	12.265 ***
	(0.629)	(0.488)	(0.893)	(0.609)
ϑ_1	4.315 ***	10.863 ***	3.948 ***	3.87 ***
	(1.46)	(0.627)	(1.104)	(0.739)
b)				
Ljung-Box lag 1	3.416 *	0.996	1.16	13.082 ***
	(0.064)	(0.318)	(0.281)	(0.0003)
Ljung-Box lag 5	7.68	8.245	3.076	19.328 ***
	(0.175)	(0.143)	(0.688)	(0.0021)
Ljung-Box lag 10	9.671	19.131 **	9.377	22.082**
	(0.47)	(0.039)	(0.497)	(0.015)

Figure 3 shows the estimated annualized realized kernel volatility for the considered countries. While the first year of the sample is characterized by low volatility in all countries, we observe a spike in May 2010 coincident with the onset of the sovereign debt crisis in Greece. On this period annualized volatility in Italy and Spain, which together with Greece, Ireland and Portugal belong to peripheral countries, is almost double than in Germany. Volatility spikes are observed also in July 2011, when the crisis reached also Italy and Spain, and, especially in these countries, in July 2012 when the redenomination risk threatened the Eurozone economy. The " Whatever it takes" speech by ECB's president Mario Draghi and the subsequent exceptional measures established by the central bank ensured a long quiet period which last until the end of 2014. A similar impact derived from the EAPP since March 2015, which served to reassure financial market from the internal instability threats, caused by, for example, the general election (Spain 2016), the government reorganization (Italy 2017), and the referendum for Brexit, which in June 2016 shook the European market.

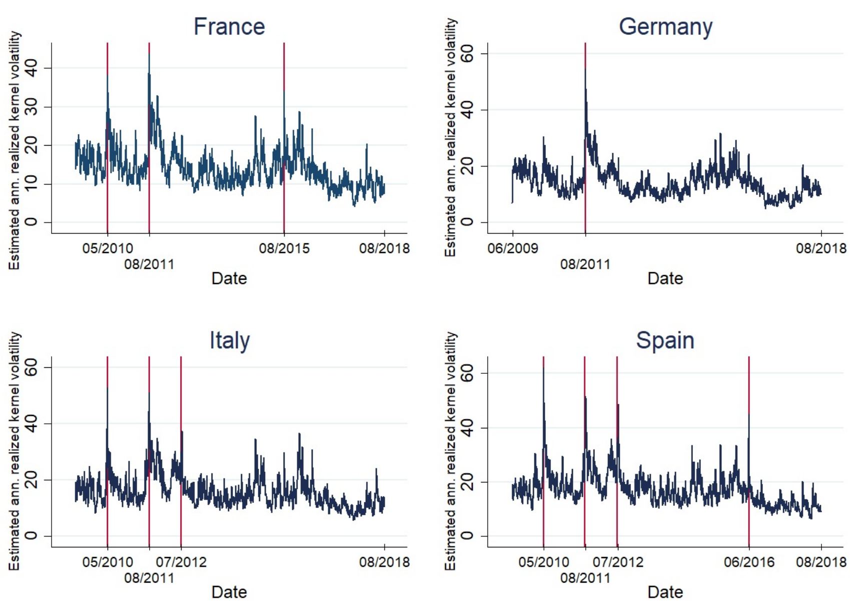

Fig. 3. CAC40, DAX30, FTSE MIB and IBEX35 estimated annualized realized kernel volatility from MS FAMEM (1 st specification). Proxy: UMP/CMP. Sample period: June 1, 2009 to August 24, 2018. Observation: 2347.

Finally, sign and significance of dummy and proxy parameters are confirmed even if we allow switching in all parameters of the third equation in (3), and it applies considering both UMP/TA (table 8) and UMP/CMP (table 9) proxies.

Therefore the analysis made for the previous specification applies also in this case, with a crucial detail that this specification successfully removes residual autocorrelation for France and Germany (while it remains for Spain).
Model persistence deserves particular attention. Contrary to the common view that high volatility persists less than low volatility, we find, for both proxies, that high volatility regime has a persistence of 0.99 for France, Germany and Spain against a low volatility persistence of about 0.94, 0.96 and 0.92 respectively. For Italy, instead, we do not find a remarkable difference in the persistence of the two regimes.
Despite the higher persistence resulting in high volatility regime, the unconventional policies seems to give a crucial contribute in maintaining volatility low, as emerges from both probabilities coefficients (tables 8 and 9) and from the computing of the average duration of regimes.
For both proxies, the probability to move from high to low regime is higher than the opposite case, for all the considered markets. More important, the average duration of low volatility regime is always higher than that of high volatility regime. The difference is large and, in particular, it equals about 13 days, 49 days, 14 days and 7 days for France, Germany, Italy and Spain, respectively (they are computed considering the UMP/CMP proxy but the results are similar if we consider the UMP/TA). In other words, it represents evidence in favour of the effectiveness of unconventional policies in reducing market volatility, despite the higher persistence in proper volatility observed in the high volatility regime.
Again, we base the selection of the best model on both information criteria and loss functions for forecasting evaluation (table 10). Generally, our proxies work better than that traditionally used in literature (total asset growth) for 3 out of 4 countries. More precisely, for Italy the preferred proxy is that measured by UMP/CMP and, according to information criteria we will choose the first specification basing on the BIC, and the second if we consider AIC; for what concerns the forecasting power, instead, the preferred specification seems to be the first one with total asset growth as a proxy for unconventional policies. Regarding information criteria, a similar status is observed for France, even though in this market the higher forecasting power is observed for the first Markov Switching specification using UMP/TA as a proxy. Finally, for the remaining countries the choice is easier, in the sense that the information criteria lead us to choose the first specification for Spain and the second for Germany with the UMP/CMP proxy in both cases. The choice based on forecasting power turns the tables: we select, indeed, the first specification for Germany and the second for Spain measuring the unconventional policies through the UMP/TA variable.

This allows us to conclude that the two proxies we consider works better than the balance sheet size growth in measuring the impact of unconventional policies on stock market volatility both in terms of goodness and forecasting.

Table 8. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the MS–FAMEM–2^{nd} specification with Proxy UMP/TA. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

a)	**France**	**Germany**	**Italy**	**Spain**
ω_0	0.657 ***	0.575 ***	0.983 ***	1.016 ***
	(0.16)	(0.097)	(0.063)	(0.022)
ω_1	0.644 ***	0.002	1.527	1.641 **
	(0.245)	(0.019)	(1.32)	(0.776)
α_0	0.124 ***	0.191 ***	0.265 ***	0.137 ***
	(0.022)	(0.019)	(0.025)	(0.025)
α_1	0.065 ***	0.02 ***	0.016	0.179 ***
	(0.014)	(0.006)	(0.027)	(0.069)
β_0	0.762 ***	0.725 ***	0.626 ***	0.738 ***
	(0.03)	(0.024)	(0.029)	(0.023)
β_1	0.935 ***	0.973 ***	0.859 ***	0.821 ***
	(0.014)	(0.006)	(0.087)	(0.069)
γ_0	0.121 ***	0.09 ***	0.083 ***	0.1 ***
	(0.015)	(0.01)	(0.018)	(0.011)
γ_1	2.70E-07	0.004	0.09 ***	6.58E-08
	(2.97E-06)	(0.003)	(0.027)	(1.55E-06)
δ	-1.693 ***	-1.114 ***	-1.439 ***	-1.814 ***
	(0.43)	(0.342)	(0.424)	(0.455)
φ	2.734 ***	2.375 ***	3.008 (0.637)	2.511 ***
	(0.541)	(0.584)	(0.637)	(0.671)
ϕ	0.152	1.34E-04	0.066	0.376
	(0.094)	(0.001)	(0.111)	(0.168)
p_{00}	0.92 ***	0.98 ***	0.938 ***	0.87 ***
	(0.059)	(0.01)	(0.044)	(0.056)
p_{11}	0.297 **	0.547 ***	0.479 **	0.057
	(0.145)	(0.03)	(0.228)	(0.065)
ϑ_0	9.477 ***	11.435 ***	15.268 ***	12.548 ***
	(0.469)	(0.416)	(1.039)	(0.718)
ϑ_1	4.268 ***	3.326 ***	4.287 ***	4.187 ***
	(1.372)	(0.981)	(1.027)	(0.84)
b)				
Ljung-Box lag 1	1.768	0.158	0.02	15.967 ***
	(0.185)	(0.691)	(0.887)	(6.444e-005)
Ljung-Box lag 5	6.512	4.038	4.454	22.355 ***
	(0.259)	(0.544)	(0.486)	(0.0004)
Ljung-Box lag 10	8.668	7.393	8.958	25.338 ***
	(0.564)	(0.688)	(0.536)	(0.005)

Table 9. CAC40, DAX30, FTSE MIB and IBEX35 annualized realized kernel volatility. **a)** Coefficients (standard error in parenthesis) and **b)** Ljung-Box statistics (p–values in parentheses) from the MS–FAMEM–2^{nd} specification with Proxy UMP/CMP. Stars are put in correspondence of small p–values: *(p–value<10%); **(p–value< 5%); ***(p–value< 1%). Sample period: June 1, 2009 to August 24, 2018. Number of observations: 2347.

a)	**France**	**Germany**	**Italy**	**Spain**
ω_0	0.696 **	0.589 ***	0.993 ***	1.07 ***
	(0.313)	(0.116)	(0.009)	(0.359)
ω_1	0.584	0.003	1.403 ***	1.484
	(0.811)	(0.018)	(0.462)	(1.207)
α_0	0.124 ***	0.19 ***	0.267 ***	0.141 ***
	(0.029)	(0.02)	(0.024)	(0.029)
α_1	0.063 *	0.019 ***	0.015	0.169
	(0.035)	(0.005)	(0.021)	(0.119)
β_0	0.759 ***	0.724 ***	0.622 ***	0.732 ***
	(0.048)	(0.025)	(0.026)	(0.04)
β_1	0.937 ***	0.973 ***	0.866 ***	0.831 ***
	(0.035)	(0.007)	(0.029)	(0.119)
γ_0	0.122	0.091 ***	0.083 ***	0.101 ***
	(0.018)	(0.01)	(0.011)	(0.014)
γ_1	2.79E-06	0.001	0.09 ***	2.57E-07
	(3.69E-05)	(0.002)	0.09 ***	(2.69E-06)
δ	-0.709 ***	-0.476 ***	-0.577 ***	-0.723 **
	(0.22)	(0.136)	(0.119)	(0.191)
φ	2.736 ***	2.384 ***	3.004 ***	2.484 ***
	(0.547)	(0.642)	(0.608)	(0.743)
ϕ	0.163	9.17E-05	0.068	0.384 ***
	(0.117)	(0.0004)	(0.083)	(0.069)
p_{00}	0.922 ***	0.98 ***	0.936 ***	0.879 ***
	(0.069)	(0.009)	(0.02)	(0.053)
p_{11}	0.292	0.55 ***	0.481 ***	0.065
	(0.344)	(0.019)	(0.02)	(0.085)
ϑ_0	9.489 ***	11.435 ***	15.326 ***	12.468***
	(0.491)	1(0.418)	(0.875)	(0.7)
ϑ_1	4.223 ***	3.302 ***	4.337 ***	4.074 ***
	(1.397)	(0.969)	(1.087)	(0.944)
b)				
Ljung-Box lag 1	1.581	0.135	0.014	14.628***
	(0.209)	(0.713)	(0.906)	(0.0001)
Ljung-Box lag 5	6.426	3.969	4.6	21.043 ***
	(0.267)	(0.554)	(0.467)	(0.0008)
Ljung-Box lag 10	8.487	7.265	9.091	23.925 ***
	(0.581)	(0.7)	(0.523)	(0.008)

Table 10. Log-likelihood, AIC, BIC, MSE, MAE for Markov Switching Factor AMEM model.

France	**Markov Switching Factor AMEM 1^{st} specification**			**Markov Switching Factor AMEM 2^{nd} specification**		
	UMP/CMP	**UMP/TA**	**TA growth**	**UMP/CMP**	**UMP/TA**	**TA growth**
Log-lik	-6823.813	-6825.978	-6844.293	**-6820.63**	-6823.001	-6832.923
AIC	5.825	5.827	5.845	**5.825**	5.827	5.838
BIC	**5.855**	5.856	5.875	5.862	5.864	5.875
MSE	29.044	**28.995**	30.609	29.459	29.462	29.325
MAE	3.789	**3.786**	3.883	3.809	3.811	3.8

Germany	**Markov Switching Factor AMEM 1^{st} specification**			**Markov Switching Factor AMEM 2^{nd} specification**		
	UMP/CMP	**UMP/TA**	**TA growth**	**UMP/CMP**	**UMP/TA**	**TA growth**
Log-lik	-6620.686	-6621.693	-6612.555	**-6588.008**	-6589.2	-6598.440
AIC	5.652	5.653	5.647	**5.627**	5.628	5.638
BIC	5.681	5.682	5.677	**5.664**	5.665	5.675
MSE	24.04	**23.825**	23.877	23.897	23.921	24.05
MAE	3.385	**3.372**	3.388	3.405	3.406	3.395

Italy	**Markov Switching Factor AMEM 1^{st} specification**			**Markov Switching Factor AMEM 2^{nd} specification**		
	UMP/CMP	**UMP/TA**	**TA growth**	**UMP/CMP**	**UMP/TA**	**TA growth**
Log-lik	-6713.422	-6713.923	-6720.566	**-6708.168**	-6708.727	-6715.122
AIC	5.731	5.731	5.74	**5.729**	5.73	5.737
BIC	**5.76**	5.761	5.769	5.766	5.766	5.774
MSE	27.446	27.474	**27.274**	28.055	28.088	28.141
MAE	3.576	3.577	**3.566**	3.587	3.589	3.596

Spain	**Markov Switching Factor AMEM 1^{st} specification**			**Markov Switching Factor AMEM 2^{nd} specification**		
	UMP/CMP	**UMP/TA**	**TA growth**	**UMP/CMP**	**UMP/TA**	**TA growth**
Log-lik	-7119.666	-7121.366	-7135.819	**-7117.397**	-7119.054	-7134.786
AIC	**6.077**	6.079	6.094	6.078	6.079	6.095
BIC	**6.107**	6.108	6.123	6.115	6.116	6.132
MSE	42.584	42.51	42.39	42.366	**42.140**	42.813
MAE	4.303	4.301	4.276	4.277	**4.269**	4.284

6 Conclusion

This paper enters in the existing literature by examining how unconventional monetary policies by ECB affect realized volatility. The innovative feature of this study lies in the model we use, the Factor AMEM, which allows us to distinguish between a pure volatility mechanism and the part of volatility depending directly on quantitative easing policies. Results show how what matters for the effectiveness of these policies is the balance sheet composition rather than the balance sheet size. Indeed, it follows that an increase in securities held by ECB for monetary policy purposes relative to total asset reduces volatility in both core and peripheral countries, with disrupted countries generally beneficing more. A further proof derives from using a different proxy, which basically tells us that an increase in securities purchased for QE programmes relative to securities held for conventional policies also reduces market volatility. However, our proxies do not allow us to distinguish the specific effect of each policies, so that we cannot identify which of these extraordinary measures is more effective. This, of course, represents a first idea for future research, as well as the possibility to control also for spillovers among countries.

Ultimately, estimating the same model within a MS model, we evaluate the contribution of these programmes in keeping volatility in low regime, i.e. the average duration of the QE effects on volatility, which is about 15 days for France, Italy and Spain. The effect lasts more in Germany, probably also because of more favourable economic conditions characterizing this country, during the sample period.

In other words, our research is a further proof that unconventional monetary policy is a crucial instrument for central banks for restoring the proper functioning of the economy and especially for achieving one of the main goals of central banks that is to preserve financial stability when interest rate is close to the zero lower bound.

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