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A HIGH FREQUENCY ASSESSMENT OF THE ECB SECURITIES MARKETS PROGRAMME

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In 2014 all ECB publications feature a motif taken from the €20 banknote.

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Abstract

Policy impact studies often suffer from endogeneity problems. Consider the case of the ECB Securities Markets Programme: If Eurosystem interventions were triggered by sudden and strong price deteriorations, looking at daily price changes may bias downwards the correlation between yields and the amounts of bonds purchased. Simple regression of daily changes in yields on quantities often give insignificant or even positive coefficients and therefore suggest that SMP interventions have been ineffective, or worse counterproductive. We use high frequency data on purchases of the ECB Securities Markets Programme and sovereign bond quotes to address the endogeneity issues. We propose an econometric model that considers, simultaneously, first and second conditional moments of market price returns at daily and intradaily frequency. We find that SMP interventions succeeded in reducing yields and volatility of government bond segments of the countries under the programme. Finally, the new econometric model is broadly applicable to market intervention studies.

JEL Codes: E52 E44 G12 C58

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Non-Technical Summary

In May 2010, the Eurosystem launched the Securities Markets Programme (SMP) to address the malfunctioning of several securities markets, which appeared to threaten the way the policy rates set by the Eurosystem are transmitted to market interest rates of longer maturity and in other market segments, to the real economy and prices. Furthermore, the ECB wanted "*to ensure depth and liquidity in those market segments which are dysfunctional. The objective of this programme [was] to address the malfunctioning of securities markets and restore an appropriate monetary policy transmission mechanism*". In practice, the Eurosystem started to intervene in the secondary markets of Greek, Irish and Portuguese government bond markets, and from August 2011 extended this to Italian and Spanish government bond markets. This paper assesses the impact of SMP purchases on the price dynamics in the government bond markets of the above sovereigns, and more specifically the impact on the yield changes and their volatility. Given the objective of the programme to address malfunctioning of securities markets, a proper assessment of these aspects is important. The paper hereby looks beyond the programmes impact at announcement which had been significant and easy to gauge. A key issue to take into account in assessing the impact of SMP purchases is the so-called endogeneity of the interventions. If interventions are triggered by sudden and strong price deteriorations, so as to avoid abrupt market changes and excess volatility, it can well be that yields are unchanged or even increased when measured over the day or week of intervention. It would be unwarranted, however, to conclude from this evidence that interventions were ineffective, or worse counterproductive, for the interventions may have prevented worse price developments.

We address the endogeneity issue by basing the analysis on short 15-minute intervals within the day to better identify the immediate price impact of purchases, while still taking into account daily developments in the model. This way we find that purchases do not have a significant impact on changes in yields at daily frequency, but retrieve the expected negative relation between purchases and yield changes at intraday frequency. The results suggest purchases have been successful in driving temporarily down yields of the countries under the programme. In addition, it is found that SMP purchases have been successful at reducing volatility of government bond yields. Arguably, containment of volatility may be the most important contribution of the SMP, given the importance certain market participants attach to it. These findings are in line with the programme objective of addressing market malfunctioning. In addition, the model is estimated using a four-week rolling window to track how the price impact changed over time. Such time-varying impact measures can be valuable input in the design and assessment of intervention programmes as the SMP. The paper presents examples of time-varying estimates and basic counterfactual exercises. Furthermore, the paper makes a methodological contribution by proposing a new class of models that is able to capture dynamics simultaneously at daily and intraday frequencies. In addition, the new class of models captures both the impact of the SMP on the level and volatility of the yields. The combination of these different elements in the model implies that the model is of independent interest beyond the study of the SMP. Finally, it is important to be clear about what this paper is not about. It does not aim at assessing the overall, long-term impact of the SMP or a fully-fledged counterfactual exercise, which would require the elaboration of a comprehensive model of the economy. We also do not look at the term structure and cross-country impact of SMP purchases, although such extensions of the model could be considered.

1 Introduction

In May 2010, the European Central Bank (ECB) and the national central banks of the euro area (the Eurosystem) launched the Securities Markets Programme (SMP) to address the malfunctioning of several securities markets. The Eurosystem started to intervene in the secondary market of Greek, Irish and Portuguese euro area government bonds, with the objective "*to ensure depth and liquidity*" and "*restore an appropriate monetary policy transmission*". After a first wave of interventions, the programme was re-activated in August 2011, when also Italian and Spanish government bond markets came under significant pressure.

The mere announcement of the central bank intervening in the secondary market had an immediate and obvious impact on government bond yields and spreads vis-à-vis Germany. For instance, spreads on ten-year Greek government bonds decreased by more than 400 basis points on 10 May 2010. Spreads on Italian and Spanish bonds decreased by almost 100 basis points on 8 August 2011, after a press release stating that the ECB would "*actively implement its Securities Markets Programme*". The impact of purchases in the following months, however, is more difficult to quantify.

A key issue to resolve in assessing the impact of SMP purchases is endogeneity. If Eurosystem interventions were triggered by sudden and strong price deteriorations, so as to avoid abrupt market changes and excessive volatility, looking at daily (or weekly) price changes may bias downwards the correlation between yields and the amounts of bonds purchased by the Eurosystem. Simple regression of daily changes in yields on quantities often give insignificant or even positive coefficients. It would be unwarranted, however, to conclude from this evidence that SMP interventions have been ineffective, or worse counterproductive.

The endogeneity problem is well-known in the foreign exchange intervention literature, see e.g. Neely (2005). An instrumental variables procedure, whereby a variable correlated with intervention but not with the shock to returns is used, would be a natural solution. However, it is very hard to find a suitable instrument in the intervention context, because intervention policy is determined by factors that could also affect the returns. Instead, as reviewed by e.g. Menkhoff (2010), several authors have employed high-frequency estimation to avoid the simultaneity bias and offer ways to deal with endogeneity. In line with this literature, in this paper we address the problem of endogeneity by resorting to high frequency data. When looking at price developments in real time, it is possible to identify the immediate price impact of bond purchases.

To fix ideas, suppose that yields increase during the day and that Eurosystem interventions are able to bring them down. By matching the timing and amounts purchased with the prevailing intraday quotes and looking at the dynamics between yields and purchases at sufficiently high frequency, it is possible to assess by how much such interventions have been successful at stemming yield increases during the day. For instance, suppose that the Eurosystem strategy were to cap yields at 5%. When looking at close of day yields, one would observe no change in yields, despite positive amounts purchased by the Eurosystem. By looking at high frequency data, however, it is possible to see that interventions are able to bring yields down every time they exceed the desired level. Zero correlation between price and quantities at daily frequency is perfectly compatible with negative correlation at higher frequency.

In fact, we do find empirical evidence that the regression coefficient obtained by regressing yield changes on SMP interventions at daily frequencies is often not significantly different from zero and in some cases even positive. When running the same regression using high frequency data sampled at 15-minute intervals, we obtain the expected negative sign, suggesting that endogeneity is indeed a serious issue for this kind of analysis. Similarly, SMP purchases have been successful at reducing volatility of government bond yields of the countries under programme. Arguably, containment of volatility may be the most important contribution of the SMP at addressing the malfunctioning of certain securities markets. Limiting volatility and avoiding abrupt market movements represent necessary conditions to guarantee proper market functioning, because large institutional investors such as pension funds and insurance companies – which are essential to ensure market depth and liquidity and which typically enforce strict risk limits – may prefer to exit excessively volatile markets, for example in order to avoid hitting their Value-at-Risk constraints.

In addition to addressing the endogeneity problem, the use of high frequency data allows us to estimate time varying elasticities of SMP interventions. We use four-week rolling window estimates to track how the price impact of Eurosystem purchases for first conditional moments have changed over time. Estimating price elasticities of Eurosystem purchases can be a valuable input in the design and assessment of the SMP purchase strategy. They help the investment manager to answer questions of the type: How many basis points can EUR 1 billion purchases lower bond yields? After how long does this effect disappear? Have the elasticities changed over time?

The paper makes also a methodological contribution, by proposing a new class of models that is able to capture dynamics simultaneously at daily and intraday frequency. In addition, the new class of models captures both the impact of the SMP on the level and the volatility of yields at the daily and intradaily level. Given the objective of the programme to address malfunctioning of securities markets, a proper assessment of these aspects is important. The combination of (1) daily/intradaily data and (2) conditional mean/volatility effects implies that our new model is of independent interest beyond the study of the SMP. In particular, the model is related to the time series approaches taken in the foreign exchange intervention literature, especially those by Beattie and Fillion (1999) and Fatum and Pedersen (2009) who relied on the model by Andersen and Bollerslev (1998) to study the impact of intervention at high frequency.

It is important to be clear about what this paper is not about. We do not aim at assessing the overall, long-term impact of the SMP or a fully fledged counterfactual exercise, which would require the elaboration of a comprehensive structural model of the economy. Such modeling, while interesting, would be fraught with difficulties and would involve substantial elements of judgement, which would inevitably affect the results. The estimation of price elasticities and the description of how they change over time, instead, is a relatively objective exercise, which can inform the SMP purchase strategy and can be used to monitor the effectiveness of the purchases over time.

We also do not look at the term structure and cross-sectional impact of SMP purchases. In principle, our modeling strategy can be used to assess whether purchases in one part of the yield curve affect prices along the term structure, or how purchases in one market affect prices of bonds of other sovereigns. In practice, it may be difficult to identify and disentangle the different effects.

Finally, it should also be noted that the empirical models we formulate focus on a single country and therefore ignore the potential cross-border spill-overs. While spill-over effects are not taken into account in the model specifications, it should be noted that these effects are not entirely absent from our analysis. For example, the announcement of SMP, which we control for can be viewed as a common factor (cross-country/ cross maturity) effect covered by our analysis. Augmenting the specifications of our models to include cross-border spill-overs would be considerably more involved and therefore left for future research. How does the fact we exclude cross-border spill-overs bias our results? It is fair to conjecture that, if anything, it would downward bias the impact of SMP we document. Hence, our findings can be viewed as producing conservative estimates.

The paper is organized as follows. The next section gives an overview of the SMP of the Eurosystem, discusses its design and its objectives, in line with the euro area debt crisis and the monetary policy transmission concerns. Section 3 discusses the possible channels through which interventions may be effective. Section 4 discusses the data, while section 5 introduces the econometric high-frequency model used in our empirical analysis. Section 6 presents the results, highlighting the different conclusions one can reach by looking at daily and intradaily data. Section 7 concludes.

2 The Securities Markets Programme

The SMP was announced on 10 May 2010 together with other measures to address severe tensions in financial markets. According to the official press release, the programme could "*conduct interventions in the euro area public and private debt securities markets to ensure depth and liquidity in those segments which are dysfunctional*". The objective of the programme was "*to address the malfunctioning of securities markets and restore an appropriate monetary policy transmission mechanism*".[1] In practice, purchases were coordinated by the ECB and carried out by the different central banks of the Eurosystem.

After a period of inactivity, the SMP was relaunched with a statement on 7 August 2011.[2] In a press release on 21 February 2013, the ECB published the Eurosystem's holdings of securities acquired under the SMP. It revealed that the Eurosystem had bought amounts for a total of EUR 218 billions. The press release reported also the breakdown for the five countries involved, Ireland, Greece, Spain, Italy and Portugal.[3]

The intervention style distinguishes the SMP from large-scale asset purchase programmes, also often referred to as quantitative easing, as introduced by e.g. the Federal Reserve and Bank of England and reviewed by Kozicki, Santor, and Suchanek (2011) and Meaning and Zhu (2011) among others. Importantly, neither the volume, nor the explicit aim to suppress longer term yields with the SMP were announced as was the case for those programmes. Moreover, even over a long period of time, SMP purchases have never reached a total volume comparable to the large-scale asset purchases of those other central banks. Only at the country level and only for certain SMP countries was the share of government bond purchases to the total amount outstanding comparable or larger than for the Federal Reserve, but still smaller than for Bank of England.

[1] See `http://www.ecb.int/press/pr/date/2010/html/pr100510.en.html` for the official statement on 10 May, 2010.

[2] See `http://www.ecb.europa.eu/press/pr/date/2011/html/pr110807.en.html` for the official statement on 7 August, 2011.

[3] See http://www.ecb.int/press/pr/date/2013/html/pr130221_1.en.html.

Clearly, the objectives, implementation and hence channels through which purchases affect markets were different. Consequently, the methods used to estimate the impact of large-scale asset purchases may not be appropriate or sufficient to identify the impact of the SMP. While the assessment of large purchases may concentrate on identifying the expected decrease in yield or spread levels, the impact channels of intervention style programmes may be more involved. The intervention style seems to be closely related to the bond market purchases by Denmark's central bank during the 1960s and 1970s to counteract rising interest rates.[4]

3 How the SMP could impact yields

Purchases of government bonds from markets that show signs of malfunctioning could impact the yields of those bonds in several ways. From an efficient market perspective, prices are purely information driven, follow economic fundamentals and purchases by the central bank can not have a price impact. In reality, however, the SMP is believed to impact bond prices in three possible ways: signalling, flow and stock channels.

First, signalling effects were clearly present. The announcement of the SMP led to an immediate drop in bond yields, as market participants anticipated Eurosystem intervention and tried to assess its magnitude, triggered by the first purchases. By its (intended) purchases the Eurosystem signals that prices are misaligned in its view and that it is prepared to counter this development. The presence of the SMP may be seen as significantly reducing the probability of a sharp deterioration in bond yields such that the right tail of the density of likely future yield outcomes shrinks and the expected yield of this density declines. The analogy with writing a put option has often been drawn. Signalling also assumes asymmetric information in that it assumes the central bank possesses information superior to that of the market as regards the outlook and future policy. The central bank reveals this information through purchases.

The impact of this signalling channel may have been time varying in the case of the SMP given that the announced action was made dependent on credible and swift government action and that the Eurosystem never committed to buy preset amounts of bonds. The upward trend in yields that took place also in the presence of the programme can be seen as driven by deteriorating expectations regarding the fiscal situation and the perceived commitment by the SMP. In contrast, the communication in the context of large-scale purchases by the Federal Reserve, as discussed in e.g. Glick and Leduc (2011), left no doubt about the parameters of the purchases.

Second, purchases are expected to trigger flow effects on prices. As SMP purchases increase demand for certain bonds, they support bond prices through their impact on the balance of buy and sell orders. To the extent that markets become one-sided with a lack of buy orders and deteriorating quotes, the flow of SMP purchases will hit the ask quotes and absorb selling orders, and thereby support the prevailing price (mid-quote and transaction price). If the encountered selling pressure is temporary, the SMP hereby offsets noisy price deviations, which may result from market malfunctioning and uncertainty in the market.

[4] See in particular 2004 publication of the Danish central bank *Financial Management at Danmarks Nationalbank*, Copenhagen, Denmark.

Capping volatility this way can be seen as having additional advantages, because volatility itself may be seen as a cause of further market malfunctioning. In particular, institutional investors have often emphasized that it is the volatility, more than the level of yields, that creates difficulties, because when markets are very volatile Value-at-Risk constraints are hit more often and some investors prefer or are forced to exit the market altogether. Capping volatility has often been put forward by market participants as an important objective for the SMP.[5]

In contrast, SMP purchases will be ineffective in defending a yield level if selling pressure is driven by new negative information. Even if the SMP would absorb large amounts offered in the market, it is unlikely to eventually keep prices away from new, lower equilibrium prices, because new information led to an increase of the credit premium. However, SMP intervention could in such a setting still be seen as "leaning against the wind" and promoting a more gradual price adjustment.

Third, stock effects may also play a role. Eurosystem security holdings resulting from SMP purchases reduce the amount of securities that can be held by other market participants, which, for reasons of imperfect asset substitutability, may have a price impact. For instance, according to the theory of "preferred habitat", investors have preferences for certain maturities and issuers, independently of their risk-return profile. Therefore, reducing the supply of specific bonds may lead to a higher price for those bonds, which is not necessarily removed by arbitrage (see Vayanos and Vila, 2009). Stock effects depend on the size of the programme. Evidence on large-scale asset purchases, e.g. by D'Amico and King (2010) suggests that SMP stock effects may have played for those countries where the share of purchases to the total outstanding amount was sizeable. One additional effect that may work in the opposite direction of stock effects relates to the preferred creditor status of the SMP. Namely, as the public sector holdings increase through SMP purchases, the loss given default of the private sector increases, which pushes yields up. As argued by Asmussen (2012), this effect may eventually have contributed to the decision to end the SMP.

The model introduced below aims to identify the impact on the level and volatility of yields. In the first place it will pick up flow effects, as it looks at high frequency yields and volatility. Second, as the stock of purchases increased its impact will also be captured by the impact coefficients. Third, the impact estimates will measure the effect of surprises stemming from purchases relative to the purchases expected by market participants. Purchases did not follow a pattern and can be considered as unpredictable as such. However, market participants may hold reasonable expectations about the amount expected over the coming period (i.e. week or month).

Given the confidentiality surrounding detailed data of SMP purchases, research on this specific programme is so far scarce and limited to the perimeter of central banks. Eickmeier (2011) finds no evidence that the first SMP launched in 2010 was effective in lowering yields, except in a temporary manner for Portugal. Another example is Fourel and Idier (2011) which proposes a theoretical microstructure model, empirically tractable that disentangle risk aversion from uncertainty in intra-

[5]For example, RBS stated: "The VaR for holding longs or shorts in Italian 5y has moved significantly for banks as volatility in bonds persists ... this is an important backdrop in assessing what the SMP can deliver", RBS presentation on "The Securities Markets Programme: drawing lessons from 2 years of ECB interventions in the government bond markets", March 2012. Bloomberg articles also often comment on volatility: "... Get involved? Or stay away? This is the question many investors asks themselves, and for sure many investors not longer involved in Italy, as the volatility scares investors away." "More importantly, we see increased risks of contagion following the surge in Spanish and Italian yields near-term. Volatility should take its toll in semi-core countries, which seem particularly vulnerable for further selling pressure...", Bloomberg, 13 June 2012.

day market quotes. They show that following the SMP implementation, the impact on uncertainty is strong given the huge impact of the programme on intraday volatility. However, this decline in uncertainty was coupled with an increase in risk aversion that may have undermined the impact of the programme on the long-term. Another paper is Eser and Schwaab (2013): The authors' baseline model suggests that, on average, a daily SMP intervention of EUR 100 million lowered yields by 0.1 to 2 basis points. This impact is stronger in markets which are smaller, less liquid, and where risk premia are higher. De Pooter, Martin, and Pruitt (2012) are interested in testing whether the SMP had an impact on sovereign bond liquidity premia. They first develop a structural search-based asset pricing model, adapted to account for default risk. In this model, agents face search frictions that prevent them from selling the asset immediately. As a consequence, the equilibrium price is lower – and the associated yield higher – than the price that would prevail in a frictionless world. The total amount purchased has been published on wire services weekly on Mondays at 15:30 C.E.T., where the amount reflects purchases settled by the previous Friday.

4 High frequency yield and purchase data

The estimation of the models presented in the next section is based on intraday observations of the prevailing bid yield of government bonds per issuer country and benchmark maturity. At higher frequency, the price deterioration triggering intervention, the intervention, and its price impact are identified more precisely in size and time, such that these events are no longer measured as occurring simultaneously. At high frequency, also the impact of other factors occurring at the time of the intervention is reduced.

The intraday government bond yields are taken from Thomson Reuters Tick Capture Engine. The security selected to be benchmark bond at a given point in time hence follows the definition by Thomson Reuters. In particular, for each of the issuer countries whose sovereign bonds were bought under the SMP, yields of the two-, five-, and ten-year benchmark bonds are considered at intraday frequencies between 8am and 6pm. Several frequencies are considered ranging from 1-minute to daily observations. Focusing on three benchmark bond yields along the yield curve allows us to contain the amount of estimations. Further, the fact that the bid side of the market captures the reaction in the price banks are willing to pay, and is not directly affected by SMP purchases because those hit the ask quotes, motivates the focus on the bid quote, but the estimates prove robust to a substitution by the mid-quote. Descriptive statistics regarding bond yields at daily and intradaily frequencies are given in Table 1.

To complete the dataset, the yield time series are matched with the total amount of SMP purchases that took place between the previous and the current yield observation. This set-up takes into account the potential impact of purchases occurring at different points of the yield curve on a specific benchmark yield. Data on Eurosystem government bond purchases under the SMP are based on Eurosystem confidential data.

One drawback is that SMP purchases are recorded with a time lag that cannot be known with precision. The recording lags are assumed to be smaller than fifteen minutes, which is the regulatory limit in place for the recording of trades by the Eurosystem. Overall, the mismatch introduces measurement error at very high frequenxcies, i.e. especially beyond 15-minute observations, preventing a full identification of the SMP impact. Therefore, the impact estimates presented below may be seen as a lower bound to the actual impact of SMP purchases.

5 A component model for government bond yields and SMP interventions

In this section we introduce a new modeling approach to study the impact of the SMP interventions. The small number of studies appraising the SMP have done so relying exclusively on daily data, with the exception already mentioned of Fourel and Idier (2011). However, the daily data may have limitations in accurately capturing market responses to Eurosystem interventions, in particular with regards to volatility responses. While the intra-daily data is better suited to study volatility dynamics, we would like to resolve the potential tensions that might exist between evidence from daily and intra-daily data. The models that exist in the literature are not designed to address simultaneously the impact of interventions at the daily and intra-daily level. Most of the original work on modeling the impact of central bank interventions has focused on foreign exchange operations. Many of these studies examine the impact of such interventions on both the volatility and the level of exchange rates but they do either exclusively with daily or intra-daily data.[6] Two exceptions are Beattie and Fillion (1999) and Fatum and Pedersen (2009) who control for daily features and intraday seasonal patterns in their intraday estimates. We propose a new class of models that simultaneously features daily and intra-daily data within one model. In addition, the new class of models captures both the impact of the SMP on the level and the volatility of yield at the daily and intra-daily level.

A key ingredient to our model specification is the use of a component structure. While component models are not new, their use to analyze central bank interventions, and to address both the high and low frequency market impacts, is new.[7] The structure we adopt is inspired by Chanda, Engle, and Sokalska (2012) who study high frequency volatility of equity returns and assume it is driven by both a daily component, with dynamics driven by daily returns, and a high frequency driven by the intra-daily returns. We adapt the insights of Chanda, Engle, and Sokalska (2012) to yields and expand their model to include SMP interventions. One of the advantages of our high frequency analysis is that it allows us to study relatively short samples, which in turn enable us to track time variation in the elasticities of SMP interventions by examining rolling sample estimates of the model with sufficient accuracy. Moreover, since the high frequency variations in yields have a daily component, we can also compare hypothetical days with and without SMP interventions via parametric restrictions.

In particular, to study the impact of the SMP both at the intraday and daily frequency, a mixed frequency component model for changes in bond yields is considered. Let $y_{i,t}$ be the yield prevailing

[6]Examples of such studies include Bonser-Neal and Tanner (1996), Beine, Bénassy-Quéré, and Lecourt (2002), Dominguez (2003), Dominguez (2006) and Beine, Lahaye, Laurent, Neely, and Palm (2007).

[7]Various authors have advocated the use of component models for volatility, arguing that a component structure is better at capturing volatility. Engle and Lee (1999) introduced a GARCH model with a long and short run component. Several others have proposed related two-factor volatility models, see e.g. Ding and Granger (1996), , Alizadeh, Brandt, and Diebold (2002), and Chernov, Gallant, Ghysels, and Tauchen (2003) among many others.

at 15-minute interval i of day t, then the change in the yields can be decomposed as

$$\Delta y_{i,t} = \frac{1}{N}\eta_t + \phi_i + \mu_{i,t} + \sqrt{\sigma_t^2 \cdot d_i^2 \cdot g_{i,t}} \cdot \varepsilon_{i,t}, \quad \forall i = 1, \ldots, N : and : t = 1, \ldots, T \tag{1}$$

where η_t (σ_t) is the daily component, ϕ_i (d_i) the intraday seasonal pattern and $\mu_{i,t}$ ($g_{i,t}$) the intraday component driving the first (second) moment of the change in yield, $\varepsilon_{i,t}|\Im_{i-1,t} \sim N(0,1)$ with $\Im_{i-1,t}$ the set of information up to $(i-1)$ of day t, N is the number of intervals in a day and T is the number of days implying $M = TN$ observations. The daily component of the first moment, η_t, is modeled as an autoregressive process with SMP purchases as explanatory variable as

$$\Delta y_t = \omega_1 + \sum_{p=1}^{P_1} \beta_p \Delta y_{t-p} + \sum_{j=0}^{J_1} \left[\gamma_{1,j} \sum_{i=1}^{N} SMP_{i,t-j} \right] + u_t = \eta_t + u_t, \tag{2}$$

with $\Delta y_t = \sum_{i=1}^{N} \Delta y_{i,t}$, u_t a Gaussian heteroscedastic error, P_1 the maximum autoregressive lag and J_1 the maximum lag, in days, attached to SMP variables. The intraday seasonal pattern is defined as

$$\phi_i = \frac{1}{T} \sum_{t=1}^{T} \left[\Delta y_{i,t} - \frac{1}{N}\eta_t \right]. \tag{3}$$

Let $x_{i,t} = \left[\Delta y_{i,t} - \phi_i - \frac{1}{N}\eta_t\right]$ be the intraday component of the first moment corrected for intraday seasonal and daily patterns, and also modeled as an autoregressive process (with maximum lag P_2) augmented with SMP purchases such that

$$x_{i,t} = \omega_2 + \sum_{p=1}^{P_2} \alpha_p x_{i-p,t} + \sum_{j=0}^{J_2} [\gamma_{2,j} SMP_{i,t-j}] + \nu_{i,t} = \mu_{i,t} + \nu_{i,t}, \tag{4}$$

with J_2 the maximum lag, in numbers of 15-min intervals, attached to SMP variables and $\nu_{i,t}$ a Gaussian heteroscedastic error term. So far, the model contains two SMP elasticities; γ_1 considers the daily sensitivity of yield levels to SMP purchases, while γ_2 considers the intraday one. The first moment of the change in yield, i.e. the first three terms of equation (1), can be estimated by sequential ordinary least squares (OLS) of (2) and (4). Computation of heteroscedasticity consistent standard errors for the parameters allows statistical inference.

The last term of (1) is modeled as a component model as in Chanda, Engle, and Sokalska (2012), augmented with SMP purchases. In particular, let the daily volatility component σ_t^2 follow a GARCH(1,1) process augmented with SMP purchases

$$\sigma_t^2 = w_1 + a_1 u_{t-1}^2 + b_1 \sigma_{t-1}^2 + \sum_{j=1}^{J_1} \left[\gamma_{3,j} u_{t-j}^2 I(SMP_{t-j} > 0) \right], \tag{5}$$

where u_{t-1} is the daily innovation in the first moment of the change in yield. To avoid that very large purchases at any point in time bias the estimated coefficient, for the volatility equation SMP purchases are introduced as a dummy variable which takes value 1 in those interval in which the Eurosystem is active, and is 0 otherwise. Furthermore, to allow for a potential asymmetric impact of the SMP, the dummy variable is interacted with the lagged squared innovations, in a similar spirit to Glosten, Jagannathan, and Runkle (1993). The intraday seasonal volatility pattern is defined as

$$d_i^2 = 1/T \sum_{t=1}^{T} \frac{\nu_{i,t}^2}{\sigma_t^2}. \tag{6}$$

Finally, we assume the volatility dynamics of the intraday component $g_{i,t}$ follow a GARCH(1,1) process also augmented with SMP purchases as

$$g_{i,t} = (1 - a_2 - b_2) + a_2 \left[\frac{\nu_{i,t-1}}{d_i \sigma_t}\right]^2 + b_2 g_{i-1,t} + \sum_{j=1}^{J_2} \left[\gamma_{4,j} \left[\frac{\nu_{i,t-j}}{d_i \sigma_t}\right]^2 I(SMP_{i,t-j} > 0)\right]. \tag{7}$$

The above model features a daily volatility process σ_t, driven by daily changes in yields and daily SMP purchases, and an intraday volatility process $g_{i,t}$, driven by intraday changes in the yield and intraday SMP purchases. The second moment of the change in yield, i.e. the last term of (1), can be estimated as a standard GARCH model via quasi maximum likelihood estimation (QMLE) of (5) and (7), i.e. assuming that the shocks $\varepsilon_{i,t}$ are i.i.d. $N(0, 1)$. From the asymptotic properties of the estimators, standard errors for the parameter estimates follow. The focus will be on estimates of γ_3 and γ_4, which relate to the impact of the SMP on volatility.

Under the null $\gamma_4 = 0$, the $g_{i,t}$ component is unit GARCH, while if $\gamma_4 \neq 0$, then it differs from unit variance by a variable that is observable, namely the SMP variable, and therefore no identification issues arise as the GARCH remains identified - note that is because the effect of the SMP variable enters additively into the GARCH dynamics. The daily GARCH specification picks up the scaling both when γ_3 and γ_4 are zero or not.

The model decomposes the yield of one bond with a specific issuer country and maturity, but the estimation could of course be applied to many bonds separately. The model can be extended by introducing yield developments and purchases of other bonds as explanatory variables to control for contagion and cross effects between several bonds. In addition, the 15-minute sampling frequency can be altered. More importantly, by introducing more lags of SMP purchases as explanatory variables, the persistence of their impact could be gauged from the value of the parameter estimates.

6 Empirical results

The model described in the previous section was estimated on two sets of data, defined as SMP1 and SMP2 corresponding to the two waves of SMP, a first wave which started in May 2010 and went through to July 2011, and a second wave which started in August 2011 and ended in February 2012. Estimations are done via sequential estimations of equations (2) - (4) using OLS for the first moment followed by an estimation via maximum likelihood of the model in equations (5) - (7) for the second moment.

6.1 The endogeneity issue

In practice, to account for the slight uncertainty about the delay with which the time stamps of SMP interventions are recorded in the Eurosystem database, the empirical specification includes the contemporaneous variable and three lags, i.e. $J_1 = J_2 = 3$.

Tables 2 contains the estimated elasticities of SMP interventions using daily data. Each coefficient reported in the table is the sum of the individual coefficients associated with all the SMP variables, that is $\gamma_{1,0}+\gamma_{1,1}+\gamma_{1,2}+\gamma_{1,3}$ for the first moment and $\gamma_{3,0}+\gamma_{3,1}+\gamma_{3,2}+\gamma_{3,3}$ for the second moment. The impact per EUR 100 million is reported in the table. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient and pertains to a Wald test that the sum of all coefficients is equal to zero. This strategy adds robustness to our estimation and ensures that SMP interventions may have a lagged impact beyond the first fifteen minutes.

Let us start with the first conditional moments. The impact of SMP is almost never significant with daily data. The exceptions are the 2-, 5- and 10-year Irish bonds during SMP2. Furthermore, even if not significant, in many instances the coefficient associated with SMP interventions has the wrong positive sign. In the case of the 2-year Italian bond, the impact is positive and statistically significant at the 10% confidence level. The literal interpretation of these estimates is that SMP interventions have at best no impact, and at worst the negative consequence of increasing yields, rather than reducing them. In practice, daily estimates suffer from obvious endogeneity problems. If the intention of the Eurosystem was to stabilize yields in the sovereign bond markets under stress, the logical strategy would be to intervene during the day each time pressure builds up. As a result of interventions, pressure would subside and yields would come down. When observed at daily frequency, however, this type of strategy would produce stable yields, despite – or rather because of – SMP interventions. Figure 1 vividly illustrates that this may indeed be the case. We plot the intraday yields and purchases of 10-year Italian bonds on an intervention day, at a fifteen-minute frequency. The negative correlation between the two series is evident from the chart. At the beginning of the day, as yields were increasing, SMP purchases manage to bring them down. In the middle of the day, as the pace of purchases slows down, yields slowly creep up. Towards the end of the day, more robust purchases manage to stabilize yields, preventing excessive increases. At the end of the day, yields close around values which were only slightly higher than those observed at the beginning. Looking only at daily frequency one would reach the wrong conclusion that SMP purchases have been completely ineffective, and that yields went up despite ECB interventions. A more careful analysis based on intraday data, however, reveals that SMP purchases have in fact been extremely effective and that they have closed only slightly higher than at the beginning of the day, because, rather than despite, of them.

Estimates for second moments are more significant, although they exhibit both negative and positive signs. In any case, it is hard to interpret results on second moments, given that first moments are erroneously estimated.

The results change dramatically when moving to intraday analysis. Table 3 reports the estimates and t-statistics of the impact of SMP1 and SMP2 interventions respectively, using intraday fifteen-minute data. As for Table 2, the elasticity of first moments refers to the SMP impact on the high frequency mean process described by the sum of the coefficients $\gamma_{2,0} + \gamma_{2,1} + \gamma_{2,2} + \gamma_{2,3}$, while the impact on the high frequency variance process of equation (7) is given by $\gamma_{4,0} + \gamma_{4,1} + \gamma_{4,2} + \gamma_{4,3}$.

We notice that the high frequency impact of SMP purchases on the mean has always the correct negative sign and very often statistically significant (Greece and Italy are exceptions in terms of significance). This suggests that using high frequency data helps us overcoming the endogeneity problems which plague analysis based on daily data. Estimates are very precise also for the second conditional moments, and unlike in the daily frequency case the sign is almost always negative (one noticeable exception being Spain). These findings suggests that the SMP has been able not only to contain upward pressures on yields, but also to have a dampening effect on their volatility.

6.2 A counterfactual exercise

To correctly gauge the long run effect of the SMP purchases, it is necessary to take into account the dynamic nature of our model. In all our specifications, we included one lagged dependent variable to take into account the autocorrelation in yield variations with $P_1 = P_2 = 1$. Therefore, SMP purchases have a direct effect on first moments via the coefficients $\gamma_{1,j}$ and $\gamma_{2,j}$, and an indirect one via the autoregressive coefficients at daily (β_1) and intradaily (α_1) frequency (see Tables 4 - 7 for all model parameters estimates). The overall impact of the SMP is thus the cumulated one over the persistence of the yield dynamics.

In Figure 2, we report the cumulative impact over time of EUR 100 million purchase for the 10-year yields during the second phase of the SMP. Results for the other maturities and the first phase of the SMP are qualitatively similar and are available upon request. We see that the long run impact of EUR 100 million ranges from 0.1 basis points for Italy to 7 basis points for Ireland.

By combining the long term impact of EUR 100 million with the SMP purchases over time, it is possible to construct the counterfactual yield that would have prevailed in the absence of SMP interventions. This is the exercise carried out in Figure 3 for the 10-year Italian government bonds. The blue line is the observed yield during the second phase of the SMP, from August 2011 to January 2012. The dashed black line represents the counterfactual yield implied by our model: it shows where the level of the Italian yield would have been in the absence of interventions. The dashed green line shows by how much SMP interventions have reduced yields over time and it is simply the difference between the counterfactual and observed yield. It is worth emphasizing that the exercise rests on the stationarity assumption of the model in the counterfactual situation of no intervention.

6.3 Rolling estimations

Another advantage of having access to high frequency data – beside solving the important problem of endogeneity – is that we can track over time the effectiveness of the SMP purchases. In Figure 4, we plot the estimated intraday elasticities (the sum of the coefficients $\gamma_{2,0} + \gamma_{2,1} + \gamma_{2,2} + \gamma_{2,3}$), obtained by re-estimating for each day the model using overlapping rolling windows of four weeks. Note that the rolling estimation only concern the high frequency component of the model, for which a sufficient number of observation is available over two weeks. This implies that the daily components of the mean and volatility are first estimated over the entire sample. The presented elasticities are hardly sensitive to the size of the window.

The case for the 10-year Italian bond is interesting. Recall from Table 3 that the overall impact based on the full sample of intraday data was only marginally significant at the 10% level. The findings based on rolling estimation qualify this result. The impact has been stable and statistically significant at the beginning of the programme, in particular during the first three months. As of mid November 2011, in the midst of high political uncertainty in Italy, the ECB scales down its interventions, whose impact also becomes statistically insignificant.

Overall, the results are qualitatively robust to the choice of different frequencies over which the data is sampled (e.g. 5 minutes and 30 minutes) and to shorter rolling windows (e.g. two weeks).

7 Conclusion

We develop a multi-frequency component model to assess the impact of SMP purchases on first and second conditional moments of changes in sovereign bond yields. The use of intraday high frequency data allows us to cope with the issue of endogeneity, while still taking into account daily developments with our multi-frequency component model. We find that SMP purchases have been successful in driving temporarily down yields of the countries under the programme and above all in capping their volatility. The fact that data quality forces a restriction on the sampling frequency, namely fifteen-minute data, may imply that the SMP impact is underestimated to some extent because the endogeneity problem is not entirely removed. The empirical analysis of this paper can be easily extended along several directions. For instance, the model focuses on the impact of total purchases along the whole yield curve on one specific yield, while the impact of purchases of a bond of a specific maturity on its yield can be expected to be higher. Furthermore, bond purchases in one jurisdiction may have a cross sectional on yields in other jurisdictions, and a proper quantification of these positive spillover effects can be obtained with an analogous empirical strategy to the one adopted in this paper.

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	es2y	es5y	es10y	gr2y	gr5y	gr10y	ie2y	ie5y	ie10y	it2y	it5y	it10y	pt2y	pt5y	pt10y
SMP1 daily															
Mean	0.02	0.03	0.03	0.14	0.10	0.09	0.07	0.07	0.06	0.02	0.02	0.03	0.07	0.07	0.06
Median	0.00	0.01	0.00	0.04	0.03	0.03	0.01	0.02	0.01	0.01	0.01	0.00	0.02	0.02	0.02
Maximum	3.48	4.73	5.44	21.5	16.5	14.7	10.6	11.1	10.2	3.05	3.90	4.82	10.9	11.2	9.46
Minimum	-0.78	-0.97	-0.67	-10.1	-6.29	-4.36	-3.39	-1.90	-1.33	-0.43	-0.66	-0.37	-2.47	-2.18	1.73
Std. Dev.	0.27	0.35	0.39	1.56	1.20	1.02	0.74	0.71	0.70	0.23	0.28	0.34	0.69	0.68	0.60
Skewness	10.4	12.1	13.1	6.6	9.3	11.6	7.8	12.1	12.9	10.7	12.3	13.4	10.6	12.6	12.8
Kurtosis	134	165	182	104	128	161	114	175	180	139	167	187	162	196	187
Observations	403	403	403	403	403	403	403	403	403	403	403	403	403	403	403
SMP1 intradaily															
Mean	0.02	0.01	0.01	0.18	0.07	0.05	0.05	0.05	0.04	0.02	0.01	0.01	0.08	0.07	0.04
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	51.2	32.3	26.3	533	363	221	117	128	48.1	50.4	35.0	24.8	129	107	50.8
Minimum	-55.6	-29.3	-22.3	-653	-374	-231	-138	-70.8	-32.1	-33.9	-27.9	-17.7	-257	-48.6	-54.3
Std. Dev.	2.63	1.46	1.19	26.01	8.64	5.29	6.09	4.09	2.50	1.82	1.42	0.92	7.15	3.66	2.80
Skewness	0.32	0.57	0.77	-0.66	-8.32	-6.16	-0.11	1.85	0.40	1.16	1.26	1.10	-3.01	1.62	0.32
Kurtosis	82	53	58	82	727	620	66	101	35	90	70	77	197	83	74
Observations	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686	16,686
SMP2 daily															
Mean	0.05	0.06	0.08	0.88	0.21	0.36	0.04	0.06	0.08	0.05	0.07	0.08	0.10	0.15	0.14
Median	0.01	0.01	0.01	0.48	0.08	0.06	0.00	0.00	-0.01	0.00	0.01	0.01	-0.03	0.00	0.00
Maximum	3.48	4.63	5.77	170	49.3	31.6	7.36	7.54	8.26	5.09	6.22	6.98	13.2	15.9	12.6
Minimum	-1.16	-1.06	-0.93	-306	-56.0	-16.8	-1.90	-0.89	-0.41	-0.88	-0.76	-0.68	-2.43	-1.77	-1.14
Std. Dev.	0.40	0.53	0.65	29.5	6.21	3.12	0.74	0.71	0.83	0.49	0.61	0.69	1.35	1.61	1.34
Skewness	6.13	7.52	8.07	-5.86	-1.53	5.93	6.08	8.07	8.51	6.75	7.70	8.37	6.21	7.75	8.07
Kurtosis	51	64	70	81	67	62	55	75	76	62	69	75	54	68	70
Observations	236	236	236	160	160	236	236	236	236	236	236	236	236	236	236
SMP2 intradaily															
Mean	0.00	0.00	0.00	4.11	0.54	0.28	-0.09	-0.06	-0.05	-0.01	0.00	0.00	-0.06	-0.06	-0.01
Median	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	26.3	25.6	33.3	2793	720	479	91.9	59.0	49.3	31.7	27.1	37.6	383	79.2	188
Minimum	-57.4	-47.6	-53.6	-2413	-618	-459	-106	-60.3	-27.4	-52.7	-38.8	-54.9	-144	-131	-64.2
Std. Dev.	2.40	2.13	1.84	267	43.0	27.0	10.5	4.98	2.89	2.90	2.41	2.10	15.6	8.09	5.25
Skewness	-1.61	-1.56	-2.95	0.45	0.51	0.18	-0.41	-0.12	0.69	-0.70	-0.09	-1.48	3.21	-0.58	8.49
Kurtosis	51	50	133	24	63	60	22	34	31	29	23	79	89	32	305
Observations	9,676	9,676	9,676	6,519	6,519	9,676	9,676	9,676	9,676	9,676	9,676	9,676	9,676	9,676	9,676

Table 1: Descriptive statistics of changes in yields (15min observations)

Bond yields are in basis points. 2 year, 5 year and 10 year maturity correspond to the benchmark on the run yields. SMP1 and SMP2 correspond to the two waves of SMP, a first wave which started in May 2010 and went through to July 2011, and a second wave which started in August 2011 and ended in February 2012. PT stands for Portugal, IE: Ireland, GR: Greece, ES: Spain, IT: Italy. Intraday data are from 08:00 AM to 6:00 PM

	SMP1			SMP2			
	PT	IE	GR	PT	IE	ES	IT
2-year Bonds							
Impact on 1st moment	-0.20	1.96*	0.42	-2.75	-90.3***	0.26	0.24*
	-0.25	1.67	0.54	-0.21	-5.60	0.98	1.78
Impact on 2nd moment	-223.59***	-38.11*	-450.14***	306.13	95.47	23.62	46.58*
	-5.27	-1.71	-4.65	1.65	0.83	1.61	1.73
5-year Bonds							
Impact on 1st moment	-0.62	0.50	0.62	-14.9	-32.7***	0.2	0.15
	-0.97	0.58	1.36	-1.35	-4.63	0.84	1.53
Impact on 2nd moment	-40.99**	4.30	-57.81	370.97*	211.59*	11.30	43.76*
	-12.09	0.91	-1.36	1.77	1.75	1.46	1.83
10-year Bonds							
Impact on 1st moment	-0.29	0.12	0.17	-4.31	-16.8***	0.10	0.055
	-0.59	0.19	0.54	-0.95	-6.06	0.50	0.64
Impact on 2nd moment	-8.47*	0.45	-57.06	-3.14	-25.59	17.39	29.26
	-1.69	0.10	-1.33	-0.15	-0.35	1.17	1.53

Table 2: ECB Securities Markets Programme Impact: Estimates with Daily Data
Entries to the table are the estimated elasticities of SMP interventions using daily data. Each coefficient reported in the table is the sum of the individual coefficients associated with all the SMP variables, that is $\gamma_{1,0} + \gamma_{1,1} + \gamma_{1,2} + \gamma_{1,3}$ for the first moment and $\gamma_{3,0} + \gamma_{3,1} + \gamma_{3,2} + \gamma_{3,3}$ for the second moment. Impact per EUR 100 million. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient. SMP1 and SMP2 correspond to the two waves of SMP, a first wave which started in May 2010 and went through to July 2011, and a second wave which started in August 2011 and ended in February 2012. PT stands for Portugal, IE: Ireland, GR: Greece, ES: Spain, IT: Italy.

	SMP1		SMP2				
	PT	IE	GR	PT	IE	ES	IT
2-year Bonds							
Impact on 1st moment	-2.76***	-1.33***	-1.22	-8.08*	-29.60***	-0.19	-0.13
	-3.36	-2.40	-1.20	-1.90	-2.98	-1.05	-1.53
Impact on 2nd moment	-0.47***	0.03***	-0.01***	-0.17***	-0.10***	0.03***	-0.01
	-38.3	7.24	-15.48	-10.2	-5.83	2.34	-0.906179
5-year Bonds							
Impact on 1st moment	-2.24***	-1.67***	-0.32	-11.70*	-27.90***	-0.29***	-0.079
	-4.05	-2.10	-0.59	-1.88	-3.47	-2.25	-1.28
Impact on 2nd moment	-0.12***	-0.049***	0.20***	0.12***	-0.17***	0.11***	-0.01***
	-44.26	-27.89	35.72	11.4	-7.22	8.12	-2.36
10-year Bonds							
Impact on 1st moment	-1.49***	-1.34***	-0.168	-5.20**	-8.2***	-0.30***	-0.08*
	-4.28	-2.46	-0.41	-2.07	-6.33	-3.20	-1.77
Impact on 2nd moment	-0.47***	-0.094***	-0.15***	-0.11***	-0.17**	0.07***	-0.03***
	-23.81	-20.86	-31.8	-15.72	-2.07	7.94	-15.1

Table 3: ECB Securities Markets Programme Impact: Estimates with intradaily Data

Entries to the table are the estimated elasticities of SMP interventions using intradaily data. Each coefficient reported in the table is the sum of the individual coefficients associated with all the SMP variables, that is $\gamma_{2,0}+\gamma_{2,1}+\gamma_{2,2}+\gamma_{2,3}$ for the first moment and $\gamma_{4,0}+\gamma_{4,1}+\gamma_{4,2}+\gamma_{4,3}$ for the second moment. Impact per EUR 100 million. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient. SMP1 and SMP2 correspond to the two waves of SMP, a first wave which started in May 2010 and went through to July 2011, and a second wave which started in August 2011 and ended in February 2012. PT stands for Portugal, IE: Ireland, GR: Greece, ES: Spain, IT: Italy.

	pt2y	ie2y	gr2y	pt5y	ie5y	gr5y	pt10y	ie10y	gr10y
ω_1	4.72***	1.17	8.24**	3.15***	1.47	3.75*	1.81**	1.37	2.29*
	2.71	0.55	2.11	2.30	1.01	1.79	1.99	1.42	1.76
β_1	0.12**	0.26***	0.17***	0.19***	0.26***	0.24***	0.17***	0.25***	0.23***
	2.15	2.38	2.64	4.40	4.02	4.02	2.52	3.33	2.92
w_1	97.22***	18.59***	274.9***	-0.03	0.95*	150.39***	2.59*	0.78	162.68***
	3.76	5.36	3.80	-0.03	1.70	5.56	1.70	1.57	6.42
a_1	0.04***	0.30***	0.35***	0.05***	0.07***	0.46***	0.21***	0.12***	0.62***
	2.41	11.07	7.58	6.35	7.53	7.87	4.91	5.32	7.23
b_1	0.94***	0.76***	0.67***	0.98***	0.94***	0.48***	0.83***	0.90***	0.18***
	54.13	44.08	15.68	186.56	154.92	8.80	25.56	48.95	2.45

Table 4: Daily parameter estimates of the component model, by country, maturity for the first wave of SMP, started in May 2010 and went through to July 2011, denoted SMP1. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient.

	pt2y	ie2y	es2y	it2y	pt5y	ie5y	es5y	it5y	pt10y	ie10y	es10y	it10y
ω_1	-1.25	3.25	-0.11	-0.99	3.61	0.01	0.08	-0.39	0.09	-0.68	0.26	0.09
	-0.30	1.34	-0.10	-0.60	0.93	0.01	0.07	-0.28	0.04	-0.60	0.27	0.09
β_1	0.23***	-0.07	0.30***	0.06	0.12	0.18*	0.19***	0.14**	0.36***	0.10	0.21***	0.14***
	2.54	-0.83	4.34	0.88	1.55	1.89	3.59	2.04	5.33	0.83	4.17	2.41
w_1	199.91*	-0.24	7.52*	16.33**	235.05***	5.4	5.27	10.04	17.58	82.08***	11.66	17.89
	1.86	-0.04	1.65	2.08	3.07	1.32	1.44	1.53	1.03	2.76	1.25	1.54
a_1	0.09***	-0.007***	0.085***	0.12***	0.13*	0.37***	0.086**	0.18***	0.05***	0.26***	0.15*	0.21**
	2.59	-6.48	2.29	3.03	1.87	5.91	2.16	3.34	3.95	2.85	1.73	2.10
b_1	0.81***	0.990 ***	0.83***	0.79***	0.75***	0.65***	0.86***	0.74***	0.92***	0.27	0.77***	0.60***
	13.18	113.38	13.23	13.54	10.00	16.73	16.34	12.00	36.64	1.31	6.73	3.44

Table 5: Daily parameter estimates of the component model, by country, maturity for the second wave of SMP, started in August 2011 and ended in February 2012, denoted SMP2. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient.

	pt2y	ie2y	gr2y	pt5y	ie5y	gr5y	pt10y	ie10y	gr10y
ω_2	0.037	0.012	0.03	0.03	0.01	0.01	0.02	0.013	0.01
	0.79	0.28	0.20	0.91	0.48	0.15	0.88	0.60	0.11
α_1	-0.25***	-0.25***	-0.31***	-0.17***	-0.15***	-0.02	-0.17***	-0.14***	-0.06
	-7.49	-11.29	-10.64	-5.19	-7.76	-0.23	-4.79	-6.93	-1.15
a_2	0.18***	0.21***	0.18***	0.17***	0.14***	0.23***	0.096***	0.11***	0.12***
	21.11	50.27	127.57	44.14	84.45	77.21	18.58	54.70	44.84
b_2	0.71***	0.72***	0.85***	0.68***	0.82***	0.69***	0.80***	0.85***	0.80***
	86.84	195.79	1773.41	123.44	580.78	279.03	113.91	680.50	278.74

Table 6: Intradaily parameter estimates of the component model, by country, maturity for the first wave of SMP, started in May 2010 and went through to July 2011, denoted SMP1. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient.

	pt2y	ie2y	es2y	it2y	pt5y	ie5y	es5y	it5y	pt10y	ie10y	es10y	it10y
ω_2	0.040	0.041	0.01	0.02	0.06	0.04	0.01	0.01	0.023	0.01	0.012	0.01
	0.33	0.51	0.33	0.49	0.69	0.93	0.62	0.34	0.55	0.42	0.71	0.47
α_1	-0.18***	-0.29***	-0.08***	0.11***	-0.10***	-0.17***	0.02	0.18***	-0.13***	-0.18***	0.08***	0.13***
	-10.3	-11.54	-2.56	4.93	-5.43	-7.19	1.19	7.77	-5.87	-8.03	2.27	6.14
a_2	0.17***	0.14***	0.14***	0.09***	0.23***	0.13***	0.10***	0.12***	0.26***	0.16***	0.13***	0.08***
	15.93	25.91	24.31	33.49	60.99	32.29	23.83	28.44	34.81	19.85	30.26	33.79
b_2	0.66***	0.77***	0.78***	0.87***	0.75***	0.82***	0.85***	0.85***	0.68***	0.77***	0.79***	0.90***
	43.65	138.00	138.21	262.68	288.72	289.17	165.56	250.71	125.49	99.32	156.73	392.45

Table 7: Intradaily parameter estimates of the component model, by country, maturity for the first wave of SMP, started in August 2011 and ended in February 2012, denoted SMP2. Stars denote significance at 10% (*), 5% (**) and 1% (***). t-statistics reported under the estimated coefficient.

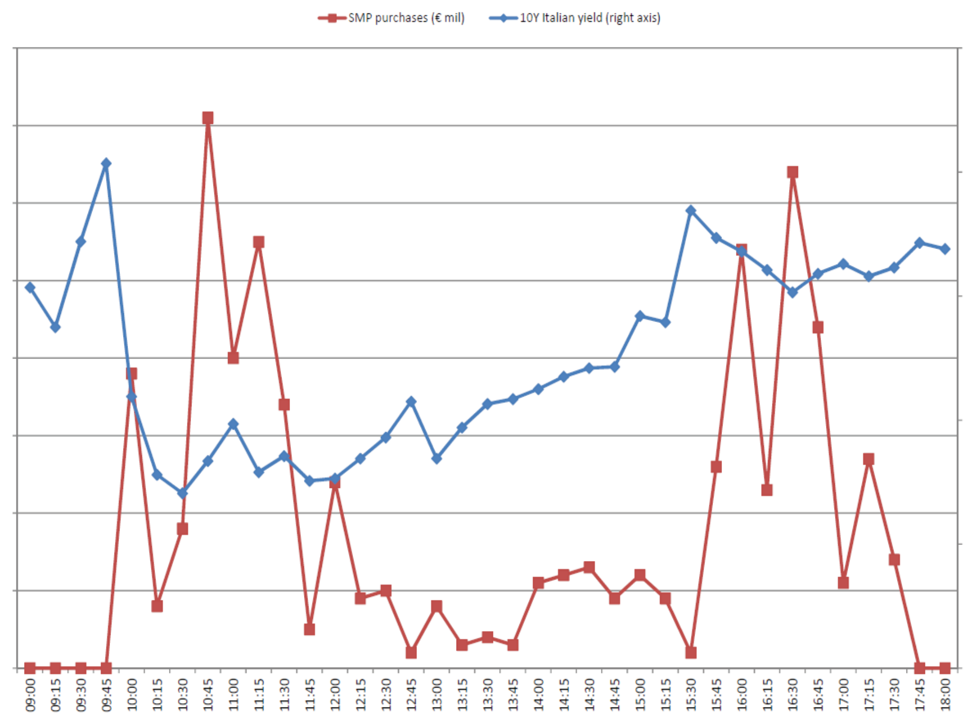


Figure 1: Illustrative developments of SMP interventions and yield dynamics over a day. The scale is not mentioned given data confidentiality.

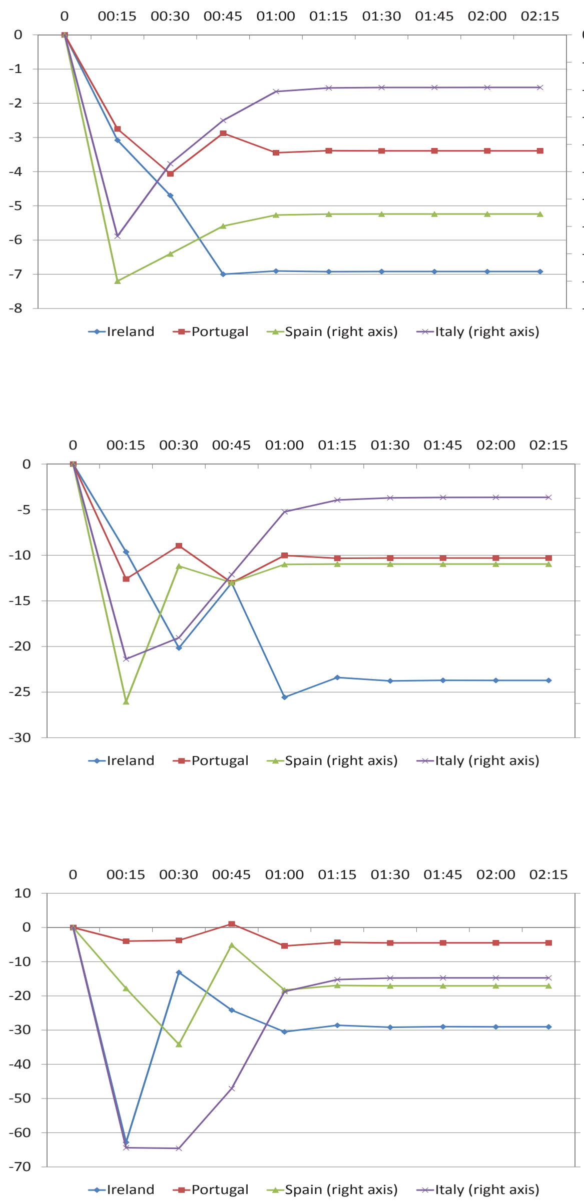


Figure 2: Impulse response functions at 15-min frequency of SMP interventions for 2-year maturity (top panel), 5-year maturity (middle panel) and 10-year maturity (low panel). Impact per EUR 100 million.

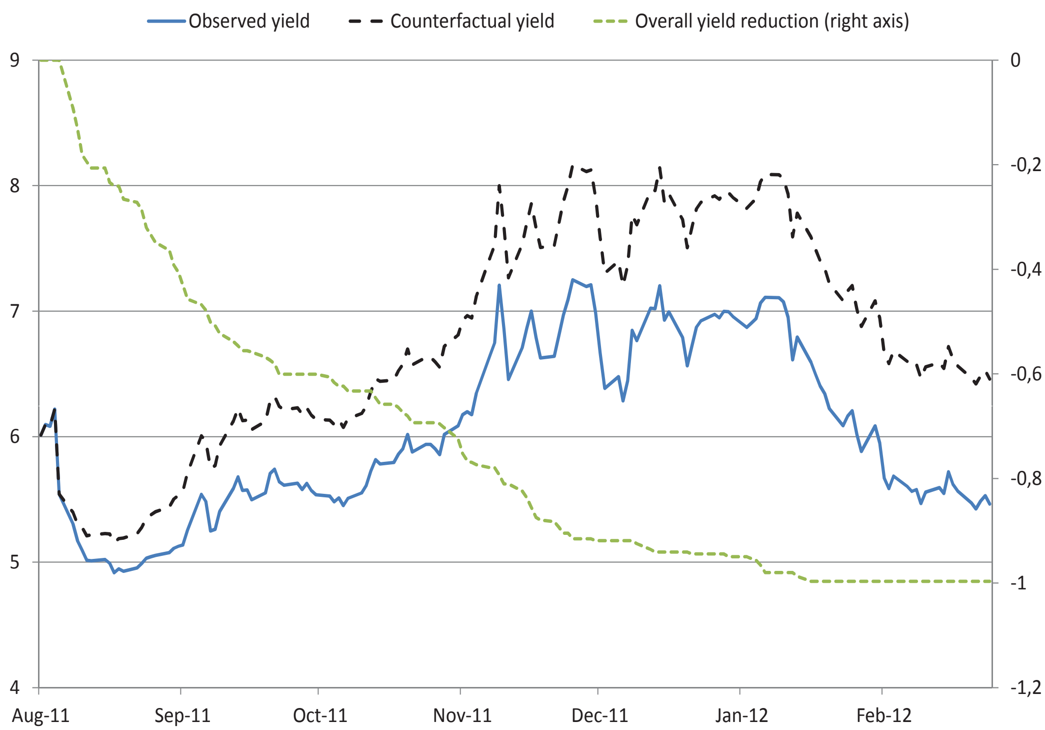
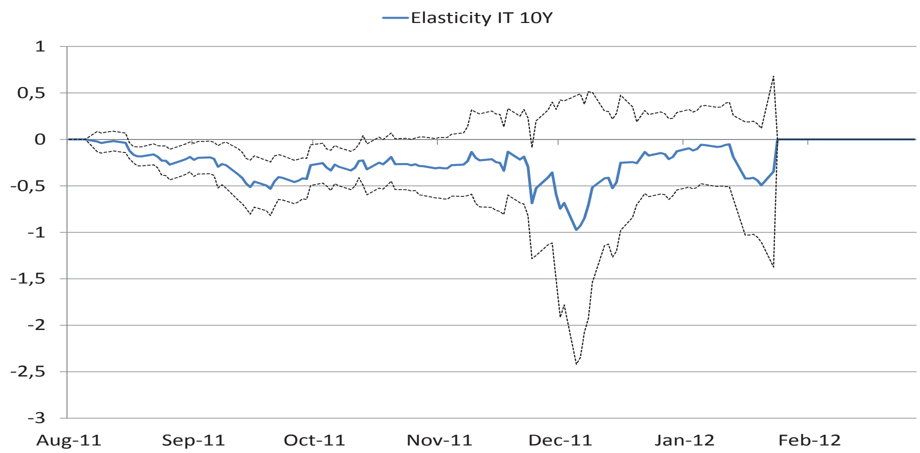


Figure 3: Counterfactual analysis for 10-year Italian Bond. The counterfactual yield is constructed by cumulating over time the long term impact of each SMP purchases, as implied by the estimated autoregressive model.



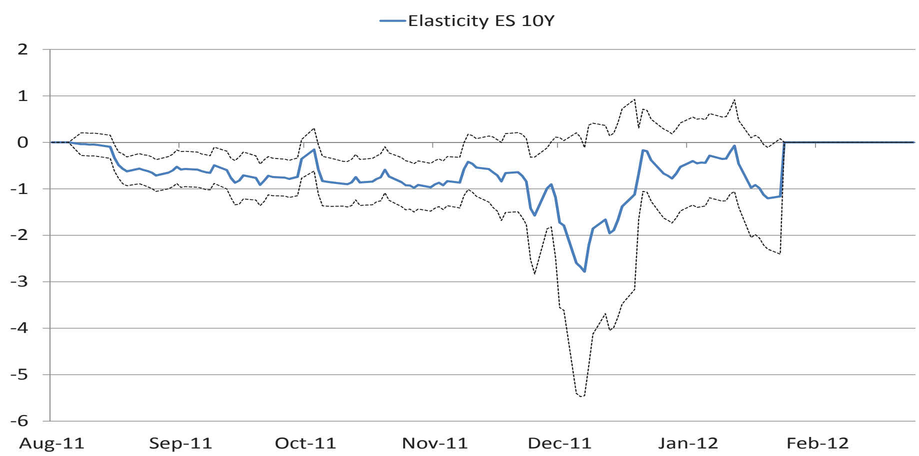


Figure 4: Rolling Estimations of intradaily yield elasticities to SMP interventions for Spain and Italy 10-year maturity bonds. The window size is 1 month. Dash lines are significance at 5%. The scale is basis points per EUR 100 Millions intervention