# A HIGH-FREQUENCY ASSESSMENT OF THE ECB SECURITIES MARKETS PROGRAMME

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**Abstract**
Policy impact studies often suffer from endogeneity problems. Consider the case of the European Central Bank (ECB) Securities Markets Programme: If Eurosystem interventions were triggered by sudden and strong price deteriorations, looking at daily price changes may bias downward the correlation between yields and the amounts of bonds purchased. Simple regressions of daily changes in yields on quantities often give insignificant or even positive coefficients and therefore suggest that Securities Markets Programme (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 simultaneity and endogeneity issues. We propose a Vector AutoRegressive (VAR) framework estimated at several frequencies to better measure the SMP impact and its persistence. Our results show that SMP interventions have been effective in reducing yields of government bonds for the countries under the program. (JEL: E52, E44, G12, C58)

## 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

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intervene via purchases 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 the first wave of interventions, the program 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 10-year Greek government bonds decreased by more than 400 basis points on May 10, 2010. Spreads on Italian and Spanish bonds decreased by almost 100 basis points on August 8, 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 downward 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 for example, 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 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 intradaily 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, we 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, as inference at higher frequency avoids the simultaneous observation problem encountered at low 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 several frequencies, we obtain the expected negative sign, suggesting that simultaneity and endogeneity are indeed a serious issue for this kind of analysis. By avoiding abrupt market movements, SMP interventions ensure 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. More specifically, for Italy and Spain we estimate the impact of SMP interventions to be about 320 and 180 basis points, respectively on 2-year yields; and 230 basis points for both countries on the 10-year ones.

In addition to addressing the simultaneity and endogeneity problems, 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 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 1 billion euros purchases lower bond yields? After how long does this effect disappear? Have the elasticities changed over time?

The paper relies on Vector AutoRegressive (VAR) models for several reasons. First, it considers endogeneity between yields and SMP interventions. Second, impulse response functions give the persistence of interventions that may fade over time. Third, the model is simple enough to be estimated at several frequencies from daily to intradaily, thus gauging the unknown impact horizon of market interventions. Finally, the simple strategy can be used for the evaluation of any policy relying on market intervention, once information on interventions is available.

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, although interesting, would be fraught with difficulties and would involve substantial elements of judgment, 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. The paper does, however, present an indicative counterfactual exercise assuming the end-of-day impact of interventions persists.

It should also be noted that the empirical models we formulate focus on a single country and therefore ignore the potential cross-border impact of the SMP. Although such 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 impact would be considerably more involved and therefore left for future research. How does the fact that we exclude cross-border impact bias our results? It is fair to conjecture that, if anything, excluding cross-border effects biases downward bias the impact of SMP we document as the impact in one country is likely to dampen yields in another country—an effect we ignore. Hence, our findings can be viewed as producing conservative estimates.

Research on the impact of the SMP is scarce and limited to the perimeter of central banks, because the detailed purchase data are still confidential. Publicly available analysis includes that by Fourel and Idier (2011) who find a strong impact of the SMP on uncertainty given the huge impact of the program on intradaily volatility. However, the authors also find that this decline in uncertainty was coupled with an increase in risk aversion that may have undermined the impact of the program in the long run. The closest contribution to ours is by Eser and Schwaab (2016), where identification is based on a daily panel regression that exploits both the cross sectional and the time series dimension of the data. They find that, after controlling for other factors, yields rose to a lesser extent in those markets in which purchases were undertaken, compared to what we would have expected based on yield developments in a larger set of euro area countries. Using the publicly available weekly SMP holdings, De Pooter, Martin, and Pruitt (2013) find statistically and economically significant effects on sovereign bonds' liquidity premia in response to purchases. The authors find an average impact of −2.3 basis points for purchases of 1/1000 of the outstanding debt of which −0.5 basis points were found to ultimately remain. Trebesch and Zettelmeyer (2014) find that the initial purchases of Greek government bonds were successful in bringing down yields between 180 and 200 basis points during the first eight weeks of the SMP.

The paper is organized as follows. The next section gives an overview of the Eurosystem's SMP, discusses its design and its objectives, in line with the euro area debt crisis and the monetary policy transmission concerns. Section 2 also describes the data. Section 3 discusses the possible channels through which interventions may be effective. Section 4 introduces the VAR model used in our empirical analysis. Section 5 presents the results, highlighting the different conclusions we can reach by looking at daily and intradaily data. Section 6 concludes.

## 2. The Securities Markets Programme

In this section we briefly describe the history of the SMP and some of its key attributes. Finally, we also provide details of the data set used in our analysis.

### *2.1. Description of SMP*

The SMP was announced on May 10, 2010 together with other measures to address severe tensions in financial markets. According to the official press release, the program could *conduct interventions in the euro area public and private debt securities markets to ensure depth and liquidity in those segments that are dysfunctional*. The objective of the program 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 August 7, 2011.[2] In a press release on February 21, 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 €218 billion. The press release reported also the breakdown for the five countries involved, Ireland, Greece, Spain, Italy, and Portugal.[3] Note that the first SMP program, henceforth referred to as SMP1, involved Greece, Ireland, and Portugal, whereas the second leg of the SMP program, henceforth SMP2, involved Ireland, Italy, Portugal, and Spain.

The intervention style, by which the quantities and types of assets purchased are unknown to the public, distinguishes the SMP from large-scale asset purchase programs, also often referred to as quantitative easing, as introduced by for example, the US Federal Reserve and the Bank of England and reviewed by Kozicki, Santor, and Suchanek (2011) and Meaning and Zhu (2011), among others. The intervention in bond markets seems to be closely related to the bond purchases by Denmark's central bank during the 1960s and 1970s to counteract rising interest rates.[4] Most importantly, neither the volume, nor the explicit aim to suppress longer term yields with the SMP were announced as was the case for quantitative easing. 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 the Bank of England.

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. Although the assessment of large purchases may concentrate on identifying the expected decrease in yield or spread levels, the impact channels of intervention style programs may be more involved.

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

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

3. See http://www.ecb.int/press/pr/date/2013/html/pr130221_1.en.html. Accessed on 29 November, 2016.

4. See in particular the 2004 publication of the Danish Central Bank, *Financial Management at Danmarks Nationalbank*, Copenhagen, Denmark.

### 2.2. *High-Frequency Yield and SMP Purchase Data*

The estimation of the models presented in Section 4 is based on intradaily observations of the prevailing mid-yield of government bonds per issuer country and benchmark maturity. At a higher frequency, we can distinguish the price deterioration triggering intervention from the price impact of the intervention.

The intradaily government bond yields are taken from Thomson Reuters Tick Capture Engine. The security selected to be benchmark bond at a given point in time therefore 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 2- and 10-year benchmark bonds are considered at intradaily frequencies between 8 a.m. and 6 p.m. Several frequencies are considered ranging from 5 min to daily observations. Focusing on two benchmark bond yields along the yield curve allows us to contain the number of models to estimate. Moreover, all models we estimate will involve changes in yields. Descriptive statistics of changes in bond yields at daily and intradaily frequencies (using 15-min data) are given in Table 1. The top panel covers SMP1 daily and intradaily, whereas the lower one does the same for SMP2—covering the countries affected by the interventions. We report the 15-min sampling frequency for the intradaily data, for reasons which will be clarified later. Comparing the daily versus intradaily, it is interesting to note that changes in yields tend to be negatively skewed. We also observe large extremes both with daily and intradaily data. It is obviously fair to say that the changes are non-Gaussian, a topic we will address—particularly in the Appendix— as discussed later.

To complete the data set, the yield time series are matched with the total amount of SMP purchases for the country that took place between the previous and the current yield observation. This setup 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 15 min, which is the regulatory limit in place for the recording of trades by the Eurosystem. Overall, the mismatch introduces measurement error at very high frequencies, i.e., especially beyond 15-min 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.

## 3. How Bond Purchases Could Impact Yields

Purchases of government bonds from market segments that show signs of stress could impact the yields of those bonds via several channels. The market intervention literature mainly suggests three different channels: (i) the impact on market conditions and especially liquidity/volatility premia, (ii) the scarcity of bonds within specific market

TABLE 1. Descriptive statistics of changes in yields—daily and intradaily.

| | gr2y | gr10y | ie2y | ie10y | pt2y | pt10y | | |
|---|---|---|---|---|---|---|---|---|
| SMP1 daily | | | | | | | | |
| Mean | 3.77 | −1.11 | 1.52 | −0.38 | 1.08 | 0.87 | | |
| Median | 1.05 | 0.10 | 0.85 | 0.00 | 1.65 | 1.90 | | |
| Maximum | 479 | 119 | 253 | 90 | 390 | 139 | | |
| Minimum | −1053 | −452 | −311 | −131 | −285 | −180 | | |
| s.d. | 99.6 | 35.7 | 45.4 | 19.4 | 43.2 | 18.5 | | |
| Skewness | −4.8 | −6.6 | −1.3 | −1.0 | 0.2 | −1.9 | | |
| Kurtosis | 50 | 81 | 20 | 9 | 32 | 37 | | |
| Observations | 325 | 325 | 325 | 325 | 325 | 325 | | |
| SMP1 intradaily | | | | | | | | |
| Mean | 0.09 | −0.03 | 0.04 | −0.01 | 0.03 | 0.02 | | |
| Median | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | |
| Maximum | 339 | 52 | 117 | 48 | 101 | 51 | | |
| Minimum | −463 | −231 | −138 | −32 | −257 | −54 | | |
| s.d. | 24.1 | 4.2 | 5.6 | 2.5 | 5.3 | 2.4 | | |
| Skewness | −0.7 | −19.1 | −0.7 | 0.2 | −9.5 | −1.3 | | |
| Kurtosis | 43 | 950 | 78 | 33 | 487 | 84 | | |
| Observations | 13,000 | 13,000 | 13,000 | 13,000 | 13,000 | 13,000 | | |
| | es2y | es10y | ie2y | ie10y | it2y | it10y | pt2y | pt10y |
| SMP2 daily | | | | | | | | |
| Mean | −2.36 | −0.60 | −4.45 | −5.32 | −1.96 | −0.45 | −10.05 | −3.71 |
| Median | −0.98 | 0.45 | −1.10 | −5.90 | −1.70 | 0.50 | −1.85 | −2.70 |
| Maximum | 48 | 43 | 109 | 91 | 86 | 45 | 394 | 181 |
| Minimum | −118 | −102 | −141 | −44 | −87 | −44 | −245 | −108 |
| s.d. | 19.1 | 15.2 | 38.0 | 15.9 | 24.2 | 13.8 | 75.3 | 30.6 |
| Skewness | −1.7 | −2.3 | −0.2 | 1.8 | −0.2 | 0.0 | 0.5 | 1.3 |
| Kurtosis | 9 | 14 | 2 | 10 | 3 | 1 | 6 | 10 |
| Observations | 148 | 148 | 148 | 148 | 148 | 148 | 148 | 148 |
| SMP2 intradaily | | | | | | | | |
| Mean | −0.06 | −0.02 | −0.11 | −0.13 | −0.05 | −0.01 | −0.25 | −0.09 |
| Median | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Maximum | 26 | 28 | 92 | 49 | 21 | 38 | 383 | 171 |
| Minimum | −57 | −54 | −106 | −27 | −53 | −15 | −144 | −50 |
| s.d. | 2.0 | 2.0 | 10.5 | 3.0 | 3.0 | 2.0 | 15.3 | 4.8 |
| Skewness | −2.5 | −5.3 | −0.5 | 0.4 | −1.1 | 1.6 | 2.4 | 7.2 |
| Kurtosis | 71 | 189 | 23 | 33 | 26 | 33 | 88 | 281 |
| Observations | 5,920 | 5,920 | 5,920 | 5,920 | 5,920 | 5,920 | 5,920 | 5,920 |

Notes: Bond yield changes are in basis points: 2- and 10-year maturities correspond to the benchmark on-the-run yields. SMP1 and SMP2 correspond to the two waves of the SMP, the first wave that started on May 10, 2010 and the second wave that started on August 8, 2011 and ended at the end of February 2012. SMP1 involved Greece, Ireland, and Portugal, whereas SMP2 involved Ireland, Italy, Portugal, and Spain. PT stands for Portugal, IE for Ireland, GR for Greece, ES for Spain, and IT for Italy. Intradaily data are from 8:00 a.m. to 6:00 p.m., sampling at the 15-min frequency.

segments, which is a channel more associated with large-scale asset purchases, i.e., depending on the size of the program, and (iii) confidence effects. This section describes the channels expected to be at work in more detail, before Section 4 presents the model that aims to capture the impact of actual interventions on yields via the combination of the channels described below. The model will not distinguish the relevance of the individual channels. Further, the paper will not directly test the “depth and liquidity” of the market or changes in the “transmission of monetary policy”, which were put forward as SMP objectives in the announcement, but assume that containing benchmark government yields creates the necessary conditions for those to materialize.

As a first potential channel, the fact that the central bank enters the market as a significant buyer can be expected to enhance the liquidity and functioning of the market and lower related premia. In less liquid markets with limited opportunities to sell, investors demand additional compensation in the form of liquidity premia for holding on to the securities. In the presence of a new large buyer, they can reduce those premia and take larger positions knowing that trading opportunities have improved. This channel appears particularly relevant given that the SMP targeted segments that were under significant strain and experienced thin trading. The relevance of this channel, which relies on presence in the market, has been underscored by Christensen and Gillan (2013) who find that purchases by the Federal Reserve reduced liquidity premia in the US TIPS market, by Gagnon et al. (2011) and Hancock and Passmore (2012) who report that purchases of mortgage-backed securities improved the functioning of that market. De Pooter, Martin, and Pruitt (2013) find that the SMP was effective in reducing liquidity premia.

Second, central bank purchases can lower yields by creating scarcity in specific market segments. This channel relies mainly on the view that investors find assets to be imperfect substitutes, which has often been explained by investors having a preferred habitat. Theories consistent with these views have been put forward at least since Culbertson (1957) and Modigliani and Sutch (1966) and were modeled more recently by Vayanos and Vila (2009). The preferred habitat view relies on the notion that investors have a preference for certain asset types (and maturities) possibly enhanced by institutional factors and regulation, which results in market segmentation. As central bank purchases reduce the supply of securities available to the private sector they create scarcity in preferred segments and can lift the price of securities in those segments. More generally, purchases could impact prices as soon as investors find that different assets are imperfect substitutes. Many empirical studies investigated this channel. For example, D’Amico and King (2013) find that the Federal Reserve’s purchase program was responsible for a persistent downward shift in US yields as it created local scarcity in maturity sectors of the US yield curve.

Third, central bank measures may affect the market assessment of the economic and risk outlooks, boosting the overall confidence in the economy. In particular, through its intervention the ECB signals that prices are misaligned in its view and is willing to counter this development, which in turn may influence market expectations. To the extent that the policy positively impacts market expectations this would be reflected in asset prices through a reduction in risk premia. Further, it has often been voiced that bond yields of stressed euro area sovereigns were driven by not only fundamentals but also financial contagion, as developments in one country create beliefs about another country, and by self-fulfilling beliefs, where sovereigns are pushed toward default despite improving fundamentals.[5] To the extent that central bank intervention counters such beliefs, it would support bond prices.

The above channels suggest that SMP purchases carry important information and this motivates the model introduced in the Section 4 that focuses on their impact. The drop in bond yields that immediately followed the announcement of the SMP reflects how market participants adjusted their expectations by anticipating the impact through the above channels. However, as the SMP objective was defined in rather general terms and no intervention amount was announced, market participants had to infer the commitment and consistency of the ECB to support the respective markets by monitoring actual interventions taking place. Therefore, actual purchases carried important information and could drive yields down by signaling commitment and influencing the expected future stock of purchases. In addition, actual purchases add more buy orders to the flow of market orders, which puts downward pressure on yields and volatility. Moreover, this market presence lifts the expectation of significant future presence in the market, which would reduce liquidity premia.

Despite the potential of the SMP in influencing yields, the SMP was constrained in what it could achieve owing to the implicit conditionality of purchases. Although the SMP was introduced at a time when specific sovereign bond yields were spiraling up and market liquidity was disappearing, it did not have the aim to unconditionally apply central bank resources to bring down yields to pre-crisis levels or to act as a backstop to governments financing costs. Instead the SMP press release stated that: The scope of the interventions will be determined by the Governing Council. In making this decision we have taken note of the statement of the euro area governments that they "will take all measures needed to meet [their] fiscal targets this year and the years ahead in line with excessive deficit procedures and of the precise additional commitments taken by some euro area governments to accelerate fiscal consolidation and ensure the sustainability of their public finances." ECB officials continued to refer to this conditionality of intervention during the lifetime of the SMP, even though it became explicit only with the launch of the Outright Monetary Transaction (OMT) program in the summer of 2012.[6]

## 4. A VAR Model for Government Bond Yields and SMP Interventions

In this section, to study the impact of the SMP both at the intradaily and daily frequencies we adopt a standard VAR framework that can be estimated at several

5. For discussion see ECB (2014): "The Determinants of Euro Area Sovereign Bond Yield Spreads during the Crisis", Monthly Bulletin Article, May 2014.

6. See, for example, Reuters (2011): "Trichet's Letter to Rome Published, Urged Cuts", September 29, 2011.

frequencies. 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.

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 using both daily or intradaily data.[7]

We propose here to rely on a simple methodology that enables us to execute our analysis at several frequencies. The VAR model also has the key advantage to consider several types of feedbacks between yields and SMP interventions, dealing with endogeneity among the different variables.

Moreover, 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 potential time variation in the elasticities of SMP interventions by examining rolling sample estimates of the model with sufficient accuracy.

More specifically, we estimate VAR models with 5, 15, 30, 60 min, and daily frequency data. All the VAR models are bivariate and country/maturity specific (though we suppress country labels to simplify notation). Namely, let $y_{m,i,t}$ be the yield for maturity $m$ prevailing at interval $i$ of day $t$ and let $SMP_{m,i,t}$ be the volume of purchases with the same time stamp and maturity. Hence, we have that

$$\begin{bmatrix} SMP_{m,i,t} \\ \Delta\tilde{y}_{m,i,t} \end{bmatrix} = \begin{bmatrix} \gamma_0^{SMP} \\ \gamma_0^{y} \end{bmatrix} + \sum_{j=1}^{Q} \Gamma_j \begin{bmatrix} SMP_{m,i-j,t} \\ \Delta\tilde{y}_{m,i-j,t} \end{bmatrix} + \begin{bmatrix} \gamma_D^{SMP} \\ \gamma_D^{y} \end{bmatrix} D_{m,i,t} + \begin{bmatrix} u_{m,i,t}^{SMP} \\ u_{m,i,t}^{y} \end{bmatrix} \tag{1}$$

for $i = Q + 1, \ldots, N$ with $\Delta\tilde{y}_{m,i,t} = \Delta y_{m,i,t} - \varphi_{m,i}$, $t = 1, \ldots, T$, $m = \{2, 10\}$ (i.e., 2- and 10-year maturities), $\varphi_{m,i}$ is the intradaily seasonal pattern for yields, $N$ is the number of intervals in a day and $T$ is the number of days implying $M = TN$ observations such that

$$\varphi_{m,i} = \frac{1}{T} \sum_{t=1}^{T} [\Delta\tilde{y}_{m,i,t}]. \tag{2}$$

Regarding the daily frequency estimation, one must note that $\Delta\tilde{y}_{m,i,t} = \Delta y_{m,t}$ (without the $i$ subscript) which simplifies the VAR accordingly. For all estimations, we control for SMP announcements in May 2010 and August 2011 with dummy variables $D_{m,i,\,t}$. This simple multivariate framework can take into account feedback loops between yields at maturity $m$ and SMP interventions on the corresponding segment of the term

7. Examples of such studies include Bonser-Neal and Tanner (1996), Beine, Bénassy-Quéré, and Lecourt (2002), Dominguez (2003), Dominguez (2006), and Beine et al. (2007).

structure. We use this simple framework at several frequencies (from intradaily to daily) and apply it to all market segments affected by interventions.

We design the VAR in such a way that SMP interventions appear first, so that we can rely on a standard Choleski-type decomposition for the impulse response functions (IRFs). Indeed, the identification is obtained by assuming that shocks to SMP interventions have a contemporaneous impact on changes in yields, but shocks to the yields impact SMP purchases only with a lag. This seems a plausible assumption about how market intervention decisions are taken. The assumption also holds mainly for high-frequency observations and less so for coarser sampling, which again favors the use of high-frequency data and is a key to the reason why using such data helps solve endogeneity issues.

Note that for tractability of the model, we made a few simplifications. First, we model the different maturities separately via bivariate models. There is of course the term structure. VAR models have been used extensively for the term structure (see, for example, Joslin et al. (2013)). Presumably SMP interventions would operate via the arbitrage across maturities. Hence, if a yield moves following an SMP intervention then by arbitrage all other yields will move along the implied term structure yield curve. With this rationale it makes perfect sense to proceed as we did. Second, we do not consider any cross-country interactions that may also have an impact on the effects we measure. Particularly relevant for the intradaily data, we also ignore the impact of SMP interventions on conditional volatility dynamics. We devote a subsection on this in the empirical analysis.

## 5. Empirical Results

The model described in the previous section is estimated using a sample from January 2010 until March 2012 for Italy, Spain, Ireland, Greece, and Portugal. Estimation is done using OLS using data sampled at 15-min frequencies and at the daily frequency.[8] In practice, to account for the slight uncertainty about the time stamps of SMP interventions are recorded in the Eurosystem database, the empirical specification includes two lags, i.e., $Q = 2$ in equation (1). The results we report are robust to the selection of longer lag lengths.

### *5.1. The Endogeneity Issue*

Table 2 contains the estimated impact of SMP interventions using daily data and 15-min intradaily data. Each coefficient reported in the table represents the cumulative impact of SMP interventions on yields after 20 periods obtained by computing Choleski impulse response functions. Stars denote significance at 10% (*), 5% (**), and

8. We also computed all empirical results using 5-, 30-, and 60-min data. The results are similar to those obtained with 15-min data. Appendix Table A.1 contains all results for 5-, 15-, 30-, and 60-minfrequencies for 10- and 2-year maturities.

TABLE 2. Elasticity estimates of yields to SMP interventions.

| | ES | IT | PT | GR | IE |
|---|---|---|---|---|---|
| | | | Panel A: 10-year maturity | | |
| Daily | −0.17 | −0.09 | −1.26 | −2.11 | 0.31 |
| | *−0.26* | *−0.13* | *−0.52* | *−0.44* | *0.21* |
| 15 min | −0.10*** | −0.09*** | −0.13*** | −0.02 | −0.12*** |
| | *−4.19* | *−3.25* | *−3.50* | *−0.18* | *−4.04* |
| | | | Panel B: 2-year maturity | | |
| Daily | 1.60 | 1.72 | 0.53 | −15.91 | 1.19 |
| | *1.06* | *0.92* | *0.21* | *−0.50* | *0.25* |
| 15 min | −0.06** | −0.11*** | −0.34*** | −0.52 | −0.14*** |
| | *−2.00* | *−2.84* | *−4.41* | *−0.44* | *−2.21* |

Notes: By country at 10-year maturity (Panel A) and 2-year maturity (Panel B) obtained by estimating the VAR model described in Section 4 and computing the 20-period ahead cumulative impact on yields of SMP interventions using Choleski impulse response functions. VAR models are estimated at 5, 15, 30, 60 min, and daily frequencies, controlling for intradaily seasonality, and SMP announcement days. Stars denote significance at 10% (*), 5% (**), and 1% (***)— all standard errors are computed using an HAC estimator using 15 lags and Bartlett kernel. The units of SMP are millions of euros and *t*-statistics are reported under the estimated coefficients.

1% (***) where all standard errors are computed using a heteroskedastic autoregressive consistent (HAC) estimator using 15 lags and Bartlett kernel. Figures 1 reports the IRFs at daily (Panel A) and 15-min (Panel B) frequencies for every country using 2- and 10-year maturity bonds.[9]

In practice, daily estimates suffer from obvious simultaneity and 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.

The first noteworthy fact is that the impact of SMP is never significant with daily data as shown in Tables 2 as well as Panel A of Figure 1. Consider the intradaily yields and purchases for a specific bond on an intervention day, at a 15-min frequency. A negative correlation between the two series at the intradaily frequency can be reconciled with a zero correlation with daily data as follows. At the beginning of the day, as yields increased, SMP purchases by the ECB managed to bring them down. In the middle of the day, as the pace of purchases slows down, yields slowly creep up. Toward the

9. The use of 20 periods across all sampling frequencies implies that we do not measure the impact at the same horizons. We do this on purpose, as our analysis is built on the idea that looking across different frequencies—and in particular looking at high frequencies will reveal the impact of SMP interventions more clearly.

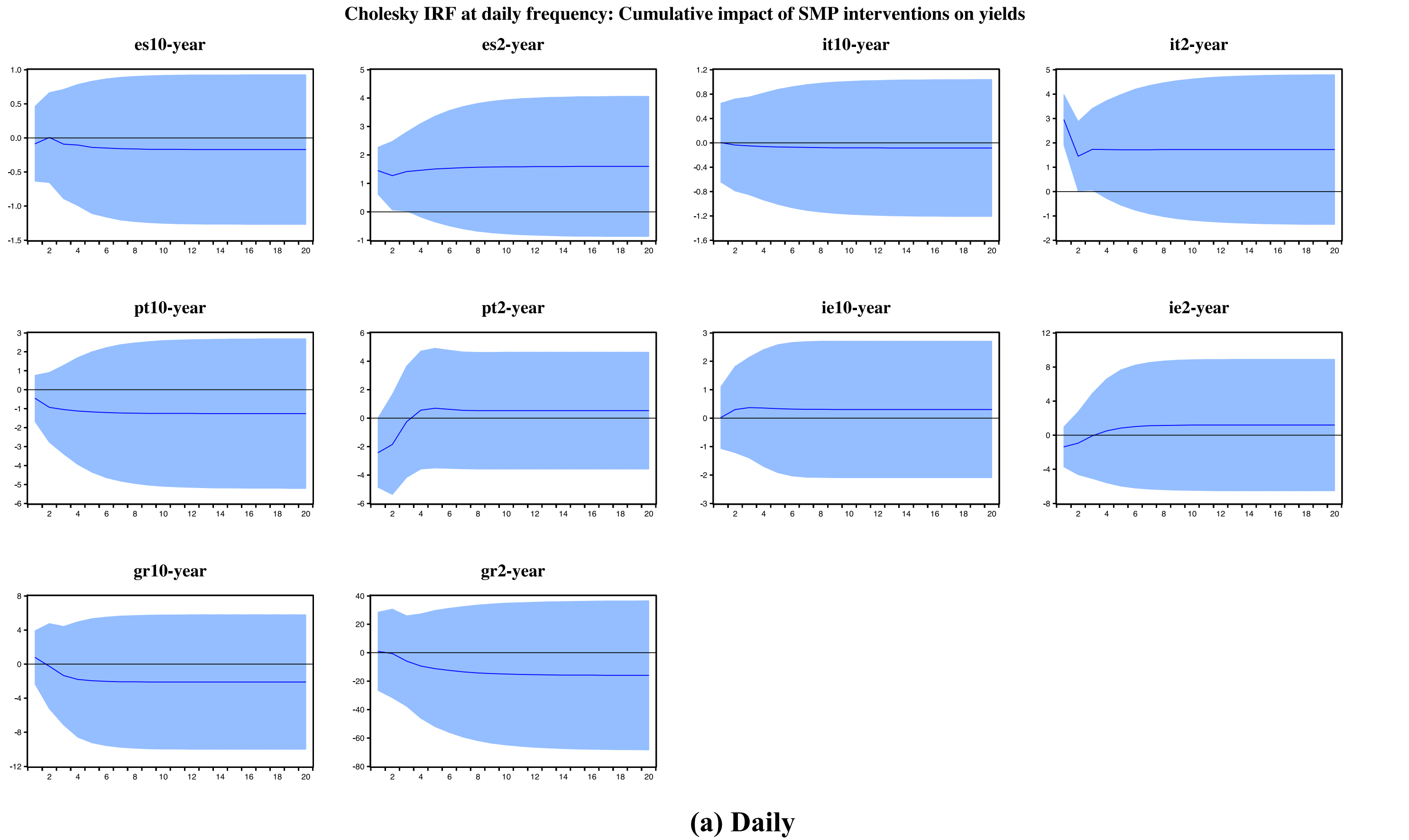


FIGURE 1. Impulse response functions daily versus intradaily. Cholesky impulse response functions for Spain, Italy, Portugal, Ireland, and Greece. They represent the impact of a one standard deviation of SMP intervention on yields at 10- and 2-year maturities, in basis points, with the 10% confidence band. Panel A: Daily and Panel B: 15 min.

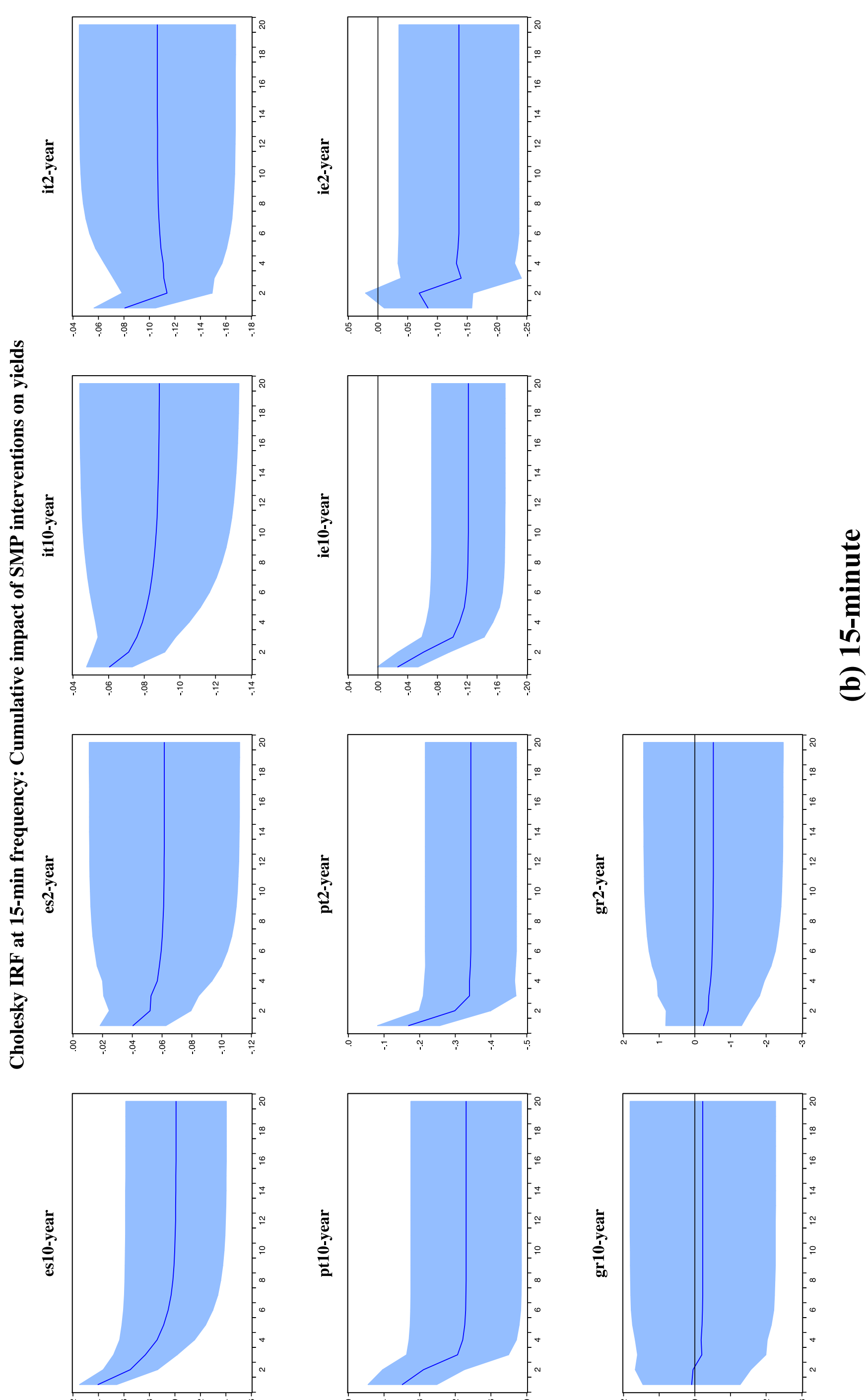


FIGURE 1. – *continued*

end of the day, more robust purchases manage to stabilize yields, preventing excessive increases. At the end of the day, yields close around values close to those observed at the beginning. Looking only at daily frequency we 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 intradaily 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.

We showed so far that the results change dramatically when we move to the intradaily analysis. Compared to daily results, we note that the high-frequency impact of SMP purchases on the yield always has the correct negative sign and is often statistically significant (Greece is an exception in terms of significance). This suggests that using high-frequency data helps us overcome the endogeneity problems that plague the analysis based on daily data. These findings suggest that the SMP has been able to effectively contain upward pressures on yields. Elasticities are not fully comparable across frequencies, because the endogeneity bias is likely to become more severe at lower frequencies. Furthermore, our VAR model is only an approximation of the true data generating process and estimates at lower frequencies are not necessarily compatible with time aggregation of higher frequency estimates. Intradaily impulse response functions in Panel B of Figure 1 also reveal that the impact is significantly persistent within a day for many countries. This therefore justified a counterfactual exercise, which we discuss in the next subsection.

Before turning our attention to counterfactual exercises, it is also worth noting that when examining the effect of the SMP on intradaily volatility, we also find highly statistically significant impacts, whatever the country and maturity.

### *5.2. The Impact of SMP Interventions on Yield Volatility*

To study the impact of the SMP both at the intraday and daily frequency on yield volatilities, we augment our VAR specification with a volatility component and estimate it with a two-step procedure. Specifically, in the first step we use the estimates from the main model of the paper, that is

$$\begin{bmatrix} SMP_{m,i,t} \\ \Delta\tilde{y}_{m,i,t} \end{bmatrix} = \begin{bmatrix} \gamma_0^{SMP} \\ \gamma_0^{y} \end{bmatrix} + \sum_{j=1}^{Q} \Gamma_j \begin{bmatrix} SMP_{m,i-j,t} \\ \Delta\tilde{y}_{m,i-j,t} \end{bmatrix} + \begin{bmatrix} \gamma_D^{SMP} \\ \gamma_D^{y} \end{bmatrix} D_{m,i,t} + \begin{bmatrix} u_{m,i,t}^{SMP} \\ u_{m,i,t}^{y} \end{bmatrix}. \quad (3)$$

In the second step, we model the variance of the VAR residual of the yield equation $u_{m,i,t}^{y}$ (which we denote with $\sigma_{m,i,t}^{2}$) with the following GARCH(1,1) process

TABLE 3. Elasticity estimates of yield volatility to SMP interventions.

| | ES | IT | PT | GR | IE |
|---|---|---|---|---|---|
| | | | Panel A: 10-year maturity | | |
| Daily | 10.142** | 37.065*** | −76.299*** | −2607.431*** | −3.430 |
| | 2.066 | 3.291 | −4.245 | −6.550 | −0.223 |
| 15 min | −0.004*** | −0.016*** | −0.289*** | 0.021*** | −0.297*** |
| | −5.624 | −27.502 | −37.369 | 55.457 | −18.131 |
| | | | Panel B: 2-year maturity | | |
| Daily | 8.672*** | 19.420* | −8.337 | −86.074*** | −45.226*** |
| | 2.908 | 1.929 | −0.483 | −3.118 | −4.473 |
| 15 min | −0.005*** | −0.021*** | −0.043*** | −0.003*** | −0.247*** |
| | −3.099 | −28.430 | −39.430 | −13.933 | −34.288 |

Notes: By country at 10-year maturity (Panel A) and 2-year-maturity (Panel B) obtained by estimating the component model at 5, 15, 30, 60-min intraday frequencies and a GARCH (1,1) at daily frequency. Stars denote significance at 10% (*), 5% (**), and 1% (***)—all standard errors are computed using an HAC estimator using 15 lags and Bartlett kernel. The units of SMP are millions of euros and $t$-statistics are reported under the estimated coefficients.

augmented with SMP purchases

$$\sigma^2_{m,i,t} = w_0 + w_1 (u^y_{m,i-1,t})^2 + w_3 \sigma^2_{m,i-1,t} + \sum_{j=1}^{J_1} \left[ \varphi_j (u^y_{m,i-j,t})^2 I(SMP_{m,i-j,t} > 0) \right]. \tag{4}$$

As can be seen from the above equation—a dummy variable is introduced which takes value 1 in those time intervals 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). We consider $J_1 = 3$ corresponding to 45-min span with 15-min sampling.

The above model features an intradaily volatility process $\sigma_t$, driven by changes in yields and SMP purchases. The parameters can be consistently estimated and standard errors computed via a two-step procedure. Namely, we estimate the VAR model first, collect the residuals and then estimate the volatility dynamics. The two-step is asymptotically consistent—see Gouriéroux (2012)—although there is a loss of efficiency. However, since we have a large number of observations, the loss in efficiency is likely to be small. Furthermore, estimating a fully specified VAR model with time-varying volatilities is a challenging exercise. In our case, the fact that the SMP variables contains many zeros and is highly skewed raises serious doubts that its volatility component can be meaningfully estimated. It therefore seems reasonable to focus only on the volatility of the changes in yields.

Table 3 reports the estimated coefficients and associated standard errors for the coefficient sum $\sum_{j=1}^{J_1} \varphi_j$. We report the daily and 15-min sampling frequencies again.[10] We observe that the impact of the SMP on the second moment of yields is negative and highly statistically significant, for most countries and maturities. The exceptions are Greece (which exhibits a positive coefficient at some maturities) and Spain and Italy at the daily frequency—confirming that also for volatility the use of daily data may produce spurious and counterintuitive results. Volatilities decrease with SMP interventions.

### *5.3. A Counterfactual Exercise*

To gauge the long run effects of the SMP purchases, we consider a counterfactual exercise for yields. The counterfactual yield implied by our model represents the level of yields in the absence of interventions. Of course, the usual caveats to this type of analysis, such as the well-known Lucas critique, apply to this type of exercise. In this simulation, we consider a 40-period long impact implied by the elasticity estimated at 15-min frequency. Note that 40 intervals of 15 min represents 10 h i.e., a day of trading for a market operating between 8 a.m. and 6 p.m. This approximates the end-of-day impact of interventions without suffering from endogeneity issues as previously underlined. This impact is added in a cumulative way to the observed yield whenever purchases occurred.

In Figure 2, we report the observed yields, the counterfactual yield without SMP intervention and the 10% confidence band around this counterfactual yields for all countries under the program, at short and long term maturities. In line with the previous estimation results, we observe that the SMP interventions were effective for all countries, at both maturities, except for Greece. For Italy and Spain, we estimate the impact to be about 320 and 180 bp, respectively on 2-year maturity yields; and 230 bp for both countries on the 10-year ones (with the necessary caution regarding parameter uncertainty about these estimates).

It is worth emphasizing, however, that the exercise reported here rests on the stationarity assumption regarding the model in the counterfactual situation of no intervention. Furthermore, the exercise also assumes a constant impact of purchases throughout the period. Next, we discuss how this changes when we implicitly allow for parameter variation via rolling sample estimates. In addition, we also formally test whether parameters are stable across time.

### *5.4. 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—via rolling sample

10. We also computed all empirical results using 5-, 30- and 60-min data. The results are similar to those obtained with 15-min data. Appendix Table A.2 contains all results for 5-, 15-, 30- and 60-minfrequencies for 10- and 2-year maturities.

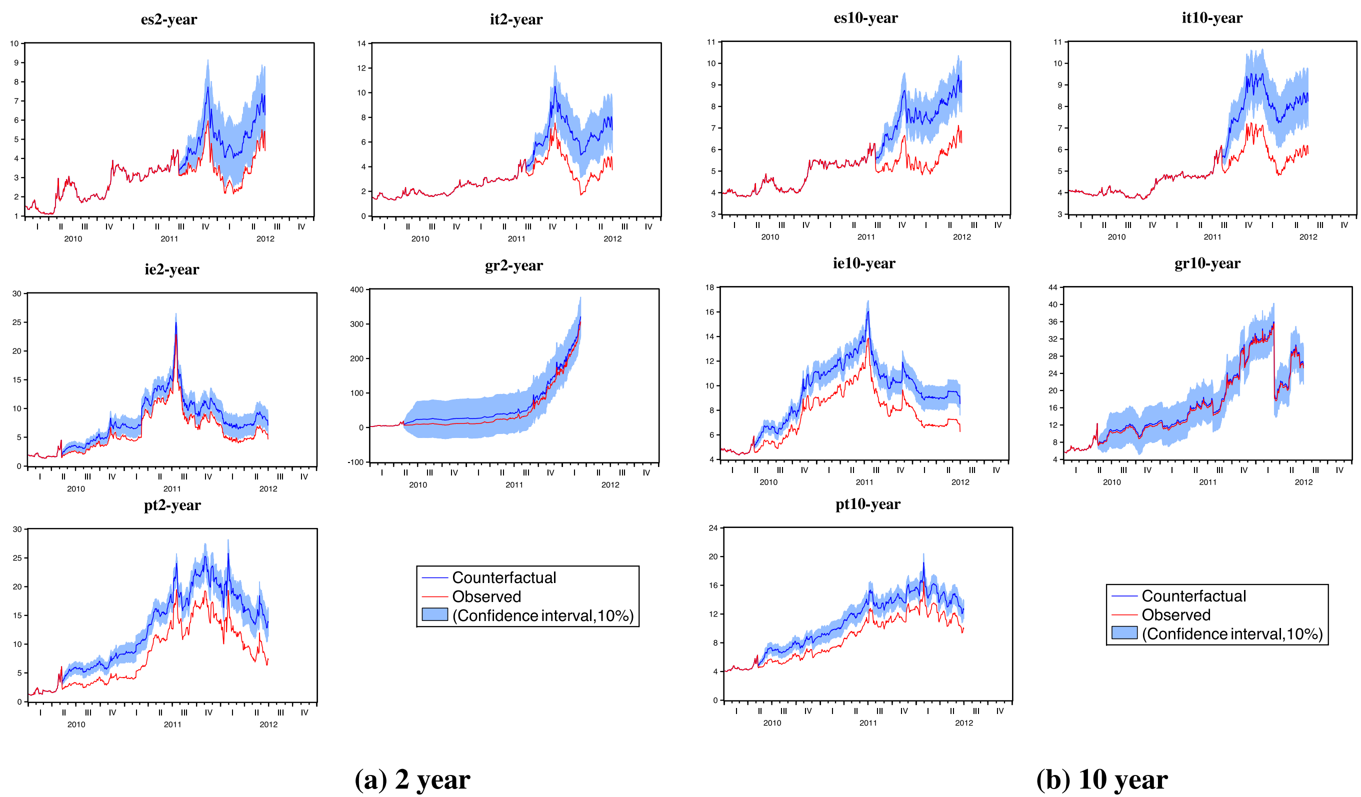


FIGURE 2. Counterfactual 2- and 10-year maturity yields for Spain, Italy, Portugal, Ireland, and Greece, using the SMP elasticities estimated at 15-min frequency and the volumes of SMP purchases for each country, each maturity segment. This counterfactual represents the yields in case of no intervention, with the 10% confidence band.

TABLE 4. Bai and Perron (2003) tests for 15-min elasticities in the VAR (equation (1)).

| Country/maturity | Break Test | $F$-stat | $F$-stat | |
|---|---|---|---|---|
| | | Panel A: VAR SMP equation | | |
| ES-2y | 0 vs. 1* | 7.99 | 15.98 | 1 break |
| ES-10y | 0 vs. 1 | 1.54 | 3.08 | No break |
| IT-2y | 0 vs. 1* | 8.15 | 16.30 | 1 break |
| IT-10y | 0 vs. 1* | 6.75 | 13.51 | 1 break |
| | | Panel B: VAR yields equation | | |
| ES-2y | 0 vs. 1 | 2.63 | 5.26 | No break |
| ES-10y | 0 vs. 1** | 8.15 | 16.30 | 1 break |
| IT-2y | 0 vs. 1 | 4.05 | 8.10 | No break |
| IT-10y | 0 vs. 1 | 3.76 | 7.53 | No break |

Notes: Panel A covers the first equation—the SMP equation and Panel B covers the second—the yields equation, * and ** denote significance at 10% and 5%, respectively. Critical Values: 9.81 (10%) and 11.47 (5%).

estimation—the effectiveness of the SMP purchases and examine the possibility of structural changes.

We examine first the issue of structural change via formal statistical testing. In particular, we apply the Bai and Perron (2003) sequential stability test applied on yield elasticities to SMP purchase in the VAR presented in equation (1) using 15-min data. Results are reported in Table 4. Panel A covers the first equation of the VAR, i.e., the SMP equation—or policy reaction function. Panel B covers the yields equation. We only report countries for which there is some evidence of structural change, namely Italy and Spain. Starting with Panel A, we find a break (and only one) for the 2-year Spanish government bonds (on August 23, 2011), for the 2-year Italian government bonds (on November 22, 2011) and for the 10-year Italian government bonds (on September 2, 2011). The presence of two or more breaks is systematically rejected in each case. Turning to Panel B, we find that the only evidence of a break is for Spain at 10-year maturity identified on November 17, 2011 at 1.15 p.m. We also find that where a single break is detected, the hypothesis for a second break hypothesis is again rejected. The evidence for a single break for Spanish 10-year bonds may anecdotally be linked to the arrival of Mario Draghi at the helm of the ECB. Indeed, after his arrival, he dropped several hints that he was in favor of discontinuing the SMP.[11]

Overall, judging by the results reported in Table 4, there appears to be only some minor evidence of structural breaks (only two countries and at most one break). Knowing that tests for structural breaks can have low power, we take an agnostic approach by also studying the rolling sample estimates of our VAR models. In Figure 3, we plot the estimated intradaily impact of SMP intervention extracted from the cumulative impulse response function after 20 periods, focusing again on Italy and

11. Although not reported it should also be noted that the results are qualitatively robust to the choice of different frequencies over which the data is sampled (for example, 5 and 30 min) and to shorter rolling windows (e.g., two weeks).

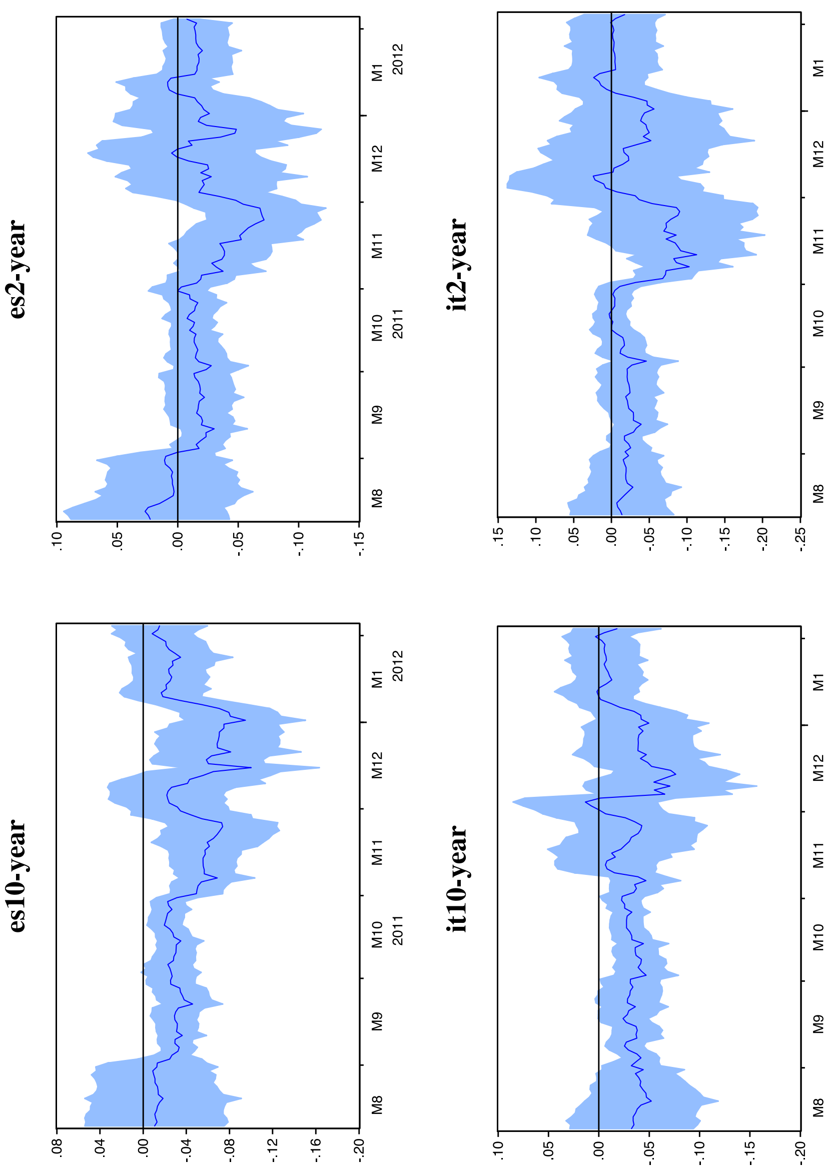


FIGURE 3. Rolling estimations of elasticities extracted from the Cholesky impulse response functions of the estimated VARs for Italy and Spain at 2 and 10-year maturities. Estimations are done at 15-min frequency, on a rolling window of four weeks, with the 10% confidence band around the estimates. The impact is expressed in basis point for 1 s.d. of SMP intervention on the corresponding segment.

Spain. The results are obtained by re-estimating the model using data sampled at 15-min frequency and overlapping rolling windows of four weeks.

We report in Figure 3 results for the 2- and 10-year maturities. Recall from Table 2 that the overall impact, based on the full sample of intradaily data, was significant at the 15-min frequency, as reflected in the counterfactual estimates previously reported. However, the findings based on rolling estimations further qualify this result. In particular, for the 2-year maturities the impact has been stable and, mainly, statistically insignificant except during specific periods of time such as November 2011. For the 10-year maturities instead the impact remains significant for most of the sample.

We observe both at the beginning and at the end of the sample that the SMP interventions did not have a significant impact. Regarding the end of the sample, we observe that SMP was no longer effective since the end of 2011—as we clearly observe a fading impact of the program on bond yields. This is perhaps not surprising, since the size of the interventions tapered off toward the end of the life time of SMP.

What about the start of SMP interventions? Recall also that we control for announcement effects in the specification of our VAR models. This explains why according to the rolling sample estimates, the first days after the SMP was introduced, the impact of interventions was not significant, as depicted in Figure 3.[12]

### *5.5. SMP Reaction Functions*

The VAR framework also gives some insights regarding the ECB reaction function pertaining to its SMP interventions. In Figure 4, we plot the rolling estimates of the SMP reaction function to a positive change in yields at 15-min frequency. From the chart no clear pattern emerges. Estimates are most of the times not significantly different from zero. Only in a few periods, are they significantly positive or negative. This is consistent with an unpredictable purchasing strategy on behalf of the ECB. Suppose that the ECB had put in place a trading rule, according to which purchases were triggered every time yields exceeded a certain threshold. In this case, market participants could have easily devised trading strategies to push yields above the trigger and then buying back at a profit. To avoid that market participants could exploit such predictable trading strategies, it is plausible to think that ECB investment managers did not systematically link their interventions to any obvious price development. In fact, anecdotal evidence confirms that trading strategies were discussed at the beginning of each week and sometimes changed during the week according to market developments. For instance, there were periods in which the ECB was trying to exploit positive market momentum and aimed at pushing yields further down (implying that purchases were triggered by negative yield changes), followed by periods in which purchases were initiated only after yields were exceeding a pre-defined threshold (implying that purchases were triggered by positive yield changes).

12. It should be noted, however, that the rolling sample estimates of the announcement effect dummies (not reported) are highly significant—in line with the usual initial impact of policy announcements.

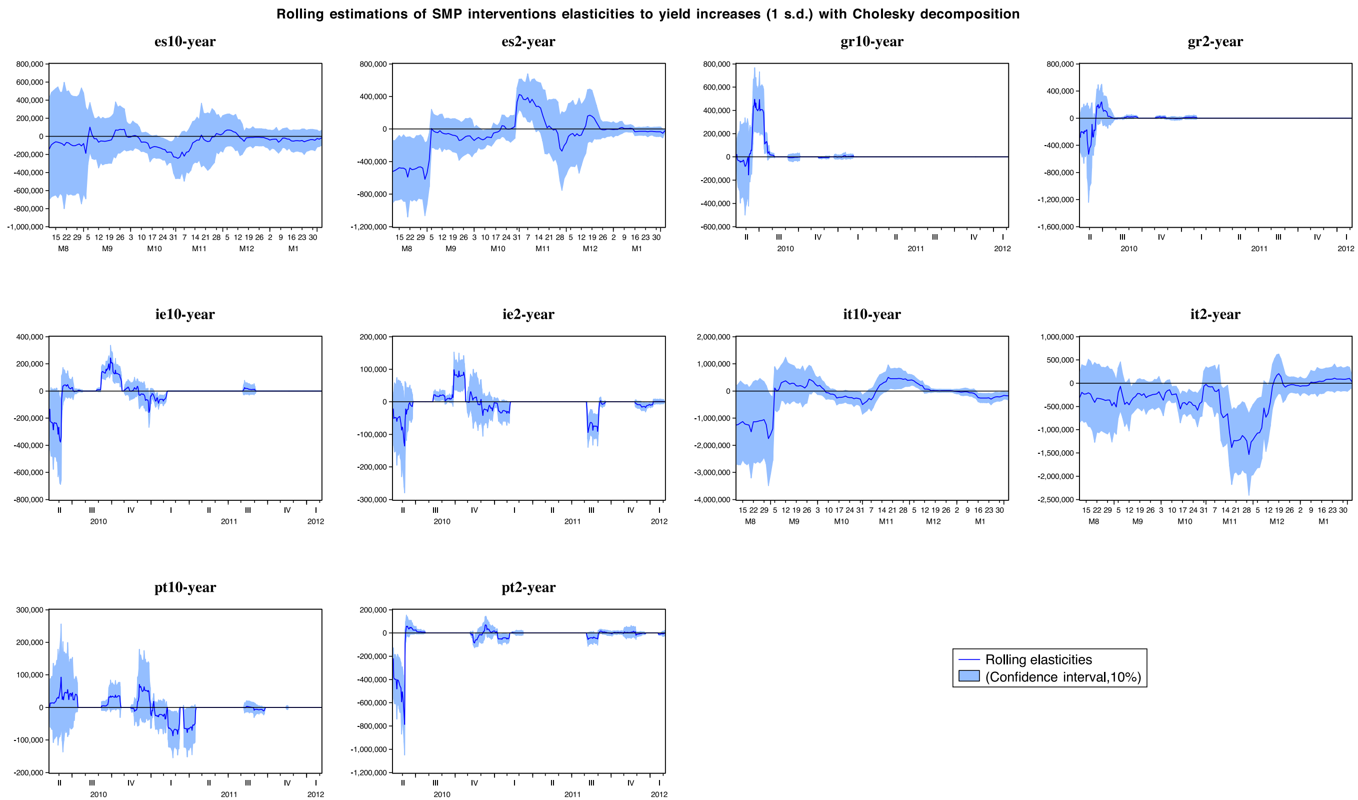


FIGURE 4. Rolling estimations of elasticities extracted from the Choleski impulse response functions of the estimated VARs for Spain, Italy, Portugal, Ireland, and Greece at 2- and 10-year maturities. They represent the impact of a 1 s.d. of yield increase on SMP intervention of the same maturity, in euros, with the 10% confidence band.

## 6. Conclusion

We proposed in this paper a VAR model to assess the impact of central bank bond purchases on bond yields, simple enough to be estimated at several frequencies, especially intradaily. The model was applied to assess the ECB SMP that was active between May 2010 and February 2012 and aimed to install necessary conditions for proper market functioning by intervening in the secondary market for sovereign bonds of Greece, Ireland, Italy, Portugal, and Spain.

Our identification strategy to rely on VAR and on high-frequency data proved vital to resolve the inherent endogeneity problem when market interventions are triggered by sudden and strong deteriorations. When such interventions are effective, yields look relatively stable at daily frequency, but simple regressions of yield changes on purchases suggest purchases are ineffective. In contrast, at high frequency, the immediate price impact of bond purchases can be better identified and the expected negative correlation between yield changes and purchases could be retrieved in the paper.

The estimates showed that SMP interventions were effective in countering upward pressure on yields of government bonds for the countries under the program, except Greece. The impact also proved significantly persistent within a day for many countries. Assuming the end-of-day impact of interventions persists, a counterfactual exercise suggested that purchases of Italian and Spanish bonds lowered 2-year yields by 320 and 180 basis points, respectively, and 10-year yields by 230 basis points for both countries. Rolling-sample estimates allowed us to qualify the results further, showing how the effectiveness of intervention varied over time and appeared to fade toward the end of the SMP when also interventions tapered off. The announcement of the SMP had a clear impact on yields and is taken into account by the model. Judging from the SMP reaction function that resulted from the VAR estimates, the ECB purchasing strategy was rather unpredictable given that most reaction coefficients were not significantly different from zero. This result is not surprising given that the interventionist has an incentive to avoid that market participants exploit predictable trading strategies.

The fact that our results show that the SMP interventions had no impact on Greek sovereign bond yields brings us back to the discussions about the purpose of the program. Our results suggest that the effectiveness of SMP interventions was limited when issues of long-term fiscal sustainability were more relevant, such as in the case of Greece.

Finally, by augmenting the VAR with a volatility component, we found a highly statistically significant dampening impact on yield volatility for most countries and maturities. This finding appears important given that the SMP aimed to counter abrupt market movements that could among others have made institutional investors leave the excessively volatile market segments.

## Appendix

TABLE A.1. Elasticity estimates of yields to SMP interventions.

| | ES | IT | PT | GR | IE |
|---|---|---|---|---|---|
| | | | Panel A: 10-year maturity | | |
| Daily | −0.17 | −0.09 | −1.26 | −2.11 | 0.31 |
| | *−0.26* | *−0.13* | *−0.52* | *−0.44* | *0.21* |
| 60 min | −0.25*** | −0.18** | −0.45*** | −0.46 | −0.54*** |
| | *−2.59* | *−2.03* | *−2.60* | *−1.02* | *−4.38* |
| 30 min | −0.18*** | −0.10*** | −0.32*** | −0.19 | −0.29*** |
| | *−3.57* | *−2.17* | *−4.47* | *−0.64* | *−6.04* |
| 15 min | −0.10*** | −0.09*** | −0.13*** | −0.02 | −0.12*** |
| | *−4.19* | *−3.25* | *−3.50* | *−0.18* | *−4.04* |
| 5 min | −0.03*** | −0.03*** | −0.03*** | −0.01 | −0.02*** |
| | *−4.68* | *−3.12* | *−2.98* | *−0.19* | *−2.39* |
| | | | Panel B: 2-year maturity | | |
| Daily | 1.60 | 1.72 | 0.53 | −15.91 | 1.19 |
| | *1.06* | *0.92* | *0.21* | *−0.50* | *0.25* |
| 60 min | −0.08 | −0.15 | −1.63*** | −3.30 | −1.25*** |
| | *−0.69* | *−1.28* | *−5.38* | *−0.74* | *−5.24* |
| 30 min | −0.09 | −0.11* | −0.98*** | −1.19 | −0.41*** |
| | *−1.60* | *−1.68* | *−6.05* | *−0.53* | *−3.21* |
| 15 min | −0.06** | −0.11*** | −0.34*** | −0.52 | −0.14*** |
| | *−2.00* | *−2.84* | *−4.41* | *−0.44* | *−2.21* |
| 5 min | −0.04*** | −0.06*** | −0.05** | −0.19 | −0.07*** |
| | *−3.95* | *−6.00* | *−2.00* | *−0.53* | *−3.47* |

Notes: By country at 10 and 2-year maturity (Panel A) and 2-year maturity (Panel B) obtained by estimating the VAR model described in Section 4 and computing the 20-period ahead cumulative impact on yields of SMP interventions using Choleski impulse response functions. VAR models are estimated at 5, 15, 30, 60 min, and daily frequencies, controlling for intradaily seasonality, and SMP announcement days. Stars denote significance at 10% (*), 5% (**), and 1% (***) —all standard errors are computed using an HAC estimator using 15 lags and Bartlett kernel. The units of SMP are millions of euros and *t*-statistics are reported under the estimated coefficients.

TABLE A.2. Elasticity estimates of yield volatility to SMP interventions.

| | ES | IT | PT | GR | IE |
|---|---|---|---|---|---|
| | | | Panel A: 10-year maturity | | |
| Daily | 8.672*** | 19.420* | −8.337 | −86.074*** | −45.226*** |
| | 2.908 | 1.929 | −0.483 | −3.118 | −4.473 |
| 60 min | −0.001 | −0.046*** | 0.017*** | −0.003*** | 0.141*** |
| | −0.181 | −9.106 | 6.060 | −2.438 | 22.545 |
| 30 min | 0.007* | −0.044*** | −0.066*** | −0.004*** | −0.008*** |
| | 1.757 | −15.215 | −21.415 | −17.985 | −2.590 |
| 15 min | −0.005*** | −0.021*** | −0.043*** | −0.003*** | −0.247*** |
| | −3.099 | −28.430 | −39.430 | −13.933 | −34.288 |
| 5 min | −0.011*** | −0.034*** | −0.270*** | −0.013*** | −0.068*** |
| | −13.518 | −59.262 | −58.538 | −164.232 | −118.736 |
| | | | Panel B: 2-year maturity | | |
| Daily | 10.142** | 37.065*** | −76.299*** | −2607.431*** | −3.430 |
| | 2.066 | 3.291 | −4.245 | −6.550 | −0.223 |
| 60 min | −0.021*** | −0.085*** | −0.015*** | 0.006*** | −0.031*** |
| | −5.861 | −16.643 | −8.149 | 14.593 | −18.570 |
| 30 min | −0.005*** | −0.046*** | −0.137*** | −0.261*** | −0.237*** |
| | −3.314 | −24.332 | −25.323 | −19.960 | −22.819 |
| 15 min | −0.004*** | −0.016*** | −0.289*** | 0.021*** | −0.297*** |
| | −5.624 | −27.502 | −37.369 | 55.457 | −18.131 |
| 5 min | −0.011*** | −0.013*** | −0.015*** | −0.003*** | −0.023*** |
| | −17.211 | −46.402 | −78.132 | −143.124 | −17.698 |

Notes: By country at 10 and 2-year maturity obtained by estimating the component model at 5, 15, 30, 60-min intraday frequencies and a GARCH (1,1) at daily frequency. Stars denote significance at 10% (*), 5% (**), and 1% (***). The units of SMP are millions of euros and *t*-statistics are reported under the estimated coefficients.

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