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Interactions of Unconventional Monetary Policy Measures with the Euro Area Yield Curve

Ľubomíra GERTLER—Faculty of National Economy, University of Economics in Bratislava (lugertler@hotmail.com)

Abstract
We study how unconventional monetary policy affects the shape of the yield curve and, conversely, the predictive power of short-run yield curve dynamics for the policy event. Two types of unconventional monetary policy measures are analysed: i) announcements and actions related to extension of central bank liquidity and ii) secondary market purchases. We find that ex-post effects on the shape of the yield curve differ substantially both in size and direction. Specifically, sovereign debt purchases are found to instantaneously lower and flatten the curve, while liquidity related actions steepen the curve, albeit mildly and for a very limited time. Further to that, the predictive power of yield curve dynamics in relation to policy implementation is supportive only for the latter signal. These findings broadly align both with the design of unconventional policy measures and with the horizon in which they are deemed to become effective.

1. Introduction

Since longer-term interest rates reflect expected movements in future short-term interest rates, studying the term structure is directly linked to the transmission of monetary policy. Due to evidence of imperfections in the transmission mechanism in the euro area, multiple unconventional monetary policy measures (hereinafter also referred to as "non-standard measures" or "NSMs") have been launched by the ECB (European Central Bank). Measuring their effect is usually limited to extracting the signal of NSM from the noise of other factors that pollute financial prices.

From the perspective of monetary policy, introduction of non-standard measures aimed to correct and/or buffer against disruptions on partial markets. In the past (prior to 2007), the standard monetary policy (interest rate setting) provided enough comfort to channel the monetary policy transmission, i.e. setting the level of the policy rate, which in combination with some (moderate and homogenous) risk premium and economic outlook was reflected in a yield curve, along which markets had operated. However, this concept has been challenged by an uncertain and volatile outlook, heterogeneous partial markets, uneven liquidity conditions and stagnant credit lines, which are all disruptive to market yield curves. Different measures have since been taken by monetary authorities to correct for market deficiencies and to ensure smooth functioning of the transmission mechanism.

This study aims to add to the quickly growing stream of literature assessing the effects of unconventional policies on debt market prices. It aspires to address differentiated assessment of debt purchases and liquidity-related measures in a common framework. Beyond measuring the effects of NSMs, it also examines the predictive power of yield curve dynamics on the launch probabilities of NSMs.

We use a sovereign yield curve concept throughout this paper to assess changes in interest rate expectations for two main reasons. First, the sovereign curve forms the basis for the maturity structure of multiple debt markets. For instance, the term structure of sovereign debt directly links to economic activity *via* decision-making about the debt financing of corporations.[1] Second, public debt plays a major role for bank finances because of its low cost properties[2] while it may serve as collateral for tapping further liquidity.

Focusing on yield curve dynamics can be justified by the fact that the shape of the yield curve incorporates effects of both standard and non-standard policy measures. Accounting for sovereign spreads on top of the yield curve dynamics is in line with the view of Lenza *et al.* (2010) that non-standard measures affect the economy *via* the interest spread.

Most of the studies carried out to date test the effectiveness of a policy signal on a specific maturity on the sovereign curve. To our view, policy is not intended to affect specific maturities; rather it is targeted at a range of maturities and/or a slope of the curve. To do this, yield curve data are extracted by applying the Nelson-Siegel (1987) interest rate structure parametric model so that a rich maturity spectrum of daily observations is simplified into three factors describing the level, slope and curvature of the yield curve. Since these three factors broadly reflect the short-term, medium-term and long-term interest rate expectations, this approach provides a handy framework for analysing the economics of yield curve dynamics.

This study has two main goals, the first of which is to assess whether NSMs have affected the shape of the yield curve, namely by the parameters of its functional form. The second goal is to assess the predictive power of changing yield curve parameters with regard to policy response, i.e. to investigate whether unconventional measures may be considered a policy response to an unfavourable shape of the yield curve (rather than the initiation signal).

We present three main empirical findings. First, we document that the signalling effect of bond purchases has a sizable impact on the level (downward shift) and the slope (flattening) of the yield curve, while announcements of liquidity-related measures do not significantly affect the shape of the yield curve. This is an update to the finding of Eser and Schwaab (2013), who claim that both announcement effects and repeated interventions have a measurable impact on the yield curve. Second, we show that unfavourable changes in the shape of the yield curve do have some predictive power for launching unconventional policy measures to counter the situation. Third, it is shown that such unfavourable yield curve developments are more likely to provoke an immediate asset purchase than is an announcement of a new liquidity-related measure. A combination of these findings suggests that movements in the shape of the yield curve and asset purchase-related measures are self-enforced, while liquidity-related measures follow more strategy-based policies.

Parameterization of the yield curve using the Nelson-Siegel type of approximation serves not only to generalise the movements in the yield curve *per se*, but also allows for discrimination between movements in the short end, long end and

[1] The shape of the maturity profile of the yield curve is altered by factors that were not as visible before the crisis, such as excess liquidity (e.g. Režňáková *et al.*, 2010, show that cash rich firms do not need to issue new debt because they would rather use free cash to finance investments) or uncertainty (e.g. Geiger, 2011, states that it applies to economies' structure and the inference of market participants).

[2] It is attributed with a zero risk weight in the calculation of regulatory ratios.

the medium term of the curve. Our results are broadly in line with the findings that central bank communication has a sizable impact up to long-term interest rates *via* changing market expectations (e.g. Brand *et al.*, 2010); however different types of non-standard measures may have diversified effects on interest rates in different maturities.

The paper is organised as follows: Section 2 elaborates on the theoretical background of the employed framework and the accompanying empirical literature that inspired this paper. Section 3 introduces the modelling framework used in the paper and Section 4 describes the data. Section 5 presents the results of the analysis and Section 6 concludes the paper.

2. Theoretical Background and Literature Overview

There has been extensive research in the area of how bond markets are priced in times of crisis and which determinants are essential for explaining market behaviour. In practical terms, these studies search the pool of fiscal and political factors that matter for credit risk and therefore shape the yield curve. In methodological terms, they either approach term structure modelling by means of equilibrium models as proposed by Vasicek (1977) or Duffee and Kan (1996), no-arbitrage models as in Hull and White (1990) or an exponential components framework employing Nelson-Siegel (1987) type interest rate structure models.

We use the latter approach mainly because it allows modeling of the yield curve with just a few parameters, describing its shape. This approach was later sharpened by Litterman and Scheinkman (1991), who constrained the yield curve dynamics to be explained by only three components, namely level, steepness (or slope) and curvature. Svensson (1994) contributed by adding a fourth component in order to further smooth the parameterisation. This smoother functional form provides more flexibility in the case of more local maxima over the yield curve. However, testing the Nelson-Siegel specification *vis-à-vis* that of Svensson provided by Gayer and Mader (1999) and confirmed by Slavik (2001) indicated that the functional form with three components provides results that are nearly as good as those provided by the form with the additional component. Due to the more intense calculus required by this additional component, we (like the majority of authors) prefer to use the three-component Nelson-Siegel specification.

Identification of common dynamic factors has become increasingly popular, especially in the past decade. Recent applications of this framework include subsequent studies by Diebold and Li (2006 and 2008), who shape the model into a neat parametric framework with a clear-cut economic interpretation and exploit the forecasting features of this approach. Later developments also count applications to global yield curve modeling or exploiting this framework on regional grounds by extracting regionally common factors (Sopov and Seidler, 2011).

The literature dealing with assessment of unconventional monetary policy measures is quite rich, assessing the effects of different measures and programmes, starting with effects of SMP, effects of announcements and communication, and single programmes such as OMT.[3]

Starting at the very beginning of the crisis, studies have focused on shocks to financial prices and their effects on economic activity. Lenza *et al.* (2010) estimated the effects of the first wave of non-standard measures, i.e. unconventional liquidity policy by assessing the effect of changes in money market rates on unemployment elasticities and industrial production. In a similar multi-country model setup, Mumtaz *et al.* (2012) confirm their findings and find that a permanent decrease in the term-spread by 100 basis points implies an increase in the level of GDP between 0.7% and 2.7%. With the recovery that followed, research further focused mostly on event studies and their effect on the term structure of interest rates.

In this vein, Eser and Schwaab (2013) used a panel regression with predetermined purchase dates within the European Central Bank's Securities Market Programme in 2010–2011 to find a measurable impact of significant announcement effects on the medium-term yields of stressed countries. Ghysels *et al.* (2014) similarly look at the SMP interventions, but they use a unique set of high-frequency data to account for endogeneity issues.[4] They find that SMP interventions succeeded in reducing yields and volatility of government bond segments of the countries under the programme; however, they fail to find effects lasting longer than several hours.

Altavilla *et al.*(2014) evaluate the effect of the announcement of the ECB's Outright Monetary Transactions adopted in 2012 in a multi-country model with macro-financial linkages. They find that, on a net basis, a two-percentage-point decline in Italian and Spanish sovereign yields may be attributed to OMTs, while no effect can be found for French and German sovereign bonds.

Studies on the effects of non-standard measures are not limited only to outcomes on financial prices, but also to trading volumes. This stream of literature addresses the fact that uncertainty has been behind hesitance to trade, while financial prices have only been the consequence of a market becoming illiquid. For this purpose, Carpenter *et al.* (2013) use the simultaneous equations approach to find that non-standard measures affected bank lending by reducing stress in bank funding markets and lowered bank funding volatility.

Besides confirming most of the observed effects from the literature in this area, this paper aims mainly at i) providing evidence using the concept of yield curve shape dynamics (which in our view is more appropriate than assessing the effect of/on single maturities) and at ii) cross-checking yield curve effects of unconventional measures with a reversed concept of policy response to yield curve dynamics.

3. The Modeling Approach

In general, the basis of the term structure modeling approach is the concept of the discount curve, forward curve and yield curve. They are linked together, as one

[3] Outright Monetary Transactions refers to the ECB-designed EFSF/ESM macroeconomic adjustment programme or precautionary programme allowing for primary market purchases on the shorter end of the yield curve under specific conditionality. The programme is elaborated in more detail on the ECB website at http://www.ecb.europa.eu/press/pr/date/2012/html/pr120906_1.en.html.

[4] The authors are concerned with the endogeneity of the SMP interventions, claiming that "[...] 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" and they use high-frequency data to address this concern. However, this concern may be resolved by working with a yield curve profile rather than with separate two-year, five-year and ten-year maturities as is the case in their study.

can use the yield curve to derive the discount curve, which then serves to derive an instantaneous forward curve.[5]

The classic Nelson-Siegel (1987) three-factor yield curve model is expressed as

$$y_t(\tau) = \beta_{1t} + \beta_{2t}\left(\frac{1-e^{-\lambda_t\tau}}{\lambda_t\tau}\right) + \beta_{3t}e^{-\lambda_t\tau} \tag{1}$$

where the left side of the equation represents the continuously compounded zero-coupon nominal yield at variable maturity and the betas are maturity-varying parameters to be estimated. Due to later criticism of the notation (1) as not being able to capture yield curves if more than one local minima or maxima are present, it is a common practice to use an enhanced form of the model as formulated by Diebold and Li (2003).

$$y_t(\tau) = f_{1t} + f_{2t}\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau}\right) + f_{3t}\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right) \tag{2}$$

This has been especially helpful in recent (crisis-related) market circumstances, when term structure variability became more imminent and the local maxima, motivated mainly by elevated credit risk, is often present between two and three years maturity. The modified formulation also allows attributing parameters with economic interpretation. The first term takes into account the level of the yield curve corresponding to the short-term factor. The second takes the slope of the curve and therefore corresponds to the factor representing the longer run. With the third term, the curvature may be attributed to the medium-term factor.[6] The three components represent loading factors, while τ represents maturity.

We use the above framework to compute loading factors, which later serve to estimate curve parameters. The point where to fix the threshold λ is selected at the local maxima of the medium-term loading factor, which is located between two and three years maturity. We retain the standard 30-month threshold of $\lambda = 0.0609$, which is also widely used in economic literature.

Starting off with a standard Nelson-Siegel (1987) model, we approximate the term structure of interest rates. We apply the Diebold and Li (2006) parametric form (3), which enhances the former to allow interpretation of coefficients as the level ($\beta_{1,t}$), slope ($\beta_{2,t}$) and curvature ($\beta_{3,t}$) of a yield curve as follows:

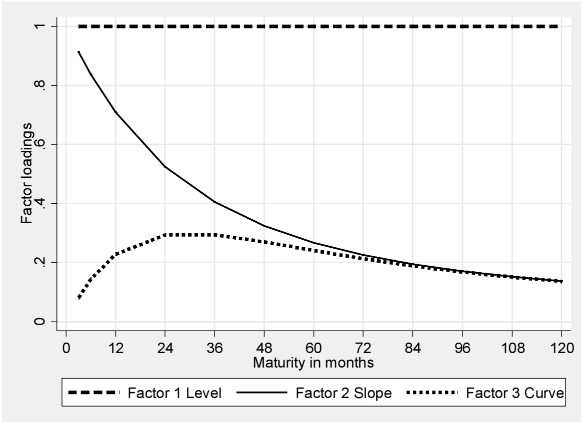
$$y_t(\tau) = \beta_{1,t} + \beta_{2,t}\left(\frac{1-e^{\lambda_t\tau}}{\lambda_t\tau}\right) + \beta_{3,t}\left(\frac{1-e^{\lambda_t\tau}}{\lambda_t\tau} - e^{\lambda_t\tau}\right) + \varepsilon_t \tag{3}$$

In (3), τ_i refers to the specific maturity i and λ is kept fixed at the value that maximises the loading on the curvature. Given the three loading factors and fixed λ,

[5] See, for example, BIS (2005) technical documentation for details.

[6] As in Diebold and Li (2006), the first loading factor β_{1t} may be viewed as a long-term factor since it is kept constant at one and does not decay to zero in the limit. Secondly, the loading on β_{2t} is $(1-e^{-\lambda\tau})/\lambda\tau$ is a function that starts at 1 but decays monotonically to 0; hence it may be viewed as a long-term factor. And lastly, the loading on β_{3t} is $(1-e^{-\lambda\tau})/\lambda\tau-e^{-\lambda\tau}$, which starts at 0 (and is thus not short-term), reaches its peak around 30 months, and then decays to zero (and thus it is not long-term); hence it may be viewed as a medium-term factor.

Figure 1 Factor Loadings of Three-Parameter Model



Source: Diebold and Li (2006).

we estimate the betas by the least squares using the yield curve data series for each observed date between January 2007 and October 2014.

The parametric form (3) allows approximating a yield curve with multiple maturities using a function of three parameters. Changes to these parameters in time express shifts in the shape of the yield curve and therefore also proxy the market perception of future market conditions. Since the data we use are synthetic euro-area yields, the changes to our observed shape of the yield curve are driven by a combination of effects from the two sources.

First, the effect originates from the traditional message of expectations that may be extracted from the shape of the yield curve (level, slope and curvature). Second, changes to the variation among individual euro-area country yield curves convey the message of heterogeneity that affects the overall (composite) shape of the yield curve. These two sources are important to distinguish both from the perspective of where disturbances in the composite curve originate as well as from the perspective of curve responses following the policy measures applied.

In order to make a clearer distinction between the two main types of unconventional measures, we separately assess signals referring to accommodation in the monetary policy *via* the liquidity channel, therefore representing a policy shift announced on a certain date. The second area of signals refers to the central bank's commitment to secondary market purchases and features the largest realised sovereign bond purchases on the market.

Monetary policy accommodation signals are thought to operate via i) support for future excess liquidity conditions and ii) provision of funds to liquidity-constrained market segments. Future excess liquidity signalled by a policy change or announcement of the allotment volume pushes the policy rate downward so that it is closer to the deposit rate or causes the policy rate to be kept there for an extended period of time. In other words, the effect on the yield curve should materialise in a downward level shift. On the other hand, loosening the liquidity conditions in the liquidity-constrained markets should mitigate risks in the medium term and therefore are expected to have a slightly downward effect on the medium-term slope, but a stimulating effect on the long-term slope of the yield curve.

Model-wise, we proceed with the analysis in two steps. First, we regress changes in the loading factor parameters $\Delta\beta_{f,t}$ on dummy variables D_i indicating announcements of unconventional measures (4a). In doing so, we document how the announcements have impacted the approximate shape of the yield curve. However, since the launching of new measures has often been motivated by heterogeneous development across the euro-area sovereigns rather than by composite indicators, the measure of sovereign bond spread s_t^B is also regressed (4b).

$$\Delta\beta_{f,t} = \alpha + \gamma D_i \tag{4a}$$

$$\Delta s_t^B = \alpha + \gamma D_i \tag{4b}$$

In the second step, we take the reverse approach and estimate a reaction function of unconventional monetary policy measures. First, we investigate whether the pattern of policy responses may be explained by the altered shape of the yield curve and/or by the dynamics of the sovereign spread. Then we look at the two types of policy responses separately and see whether the reaction function may be distinguished according to the type of policy intervention (i.e. liquidity-related announcements and direct secondary market purchases).

We do this by constructing a logistic regression, and we ask whether policy responses are driven by changes in the shape of the yield curve and/or in the sovereign spread. More specifically, we compute marginal effects and assess responses in terms of whether the probability of launching an unconventional measure increases after specific movement in the shape of the yield curve or changes to the sovereign spread.

In practice, we regress a binary variable (denoting a dummy variable of the date of action) on the three loading factors (level, slope and curvature) estimated earlier in (3) and the term representing the sovereign spread. We use a cumulative standard logistic density function

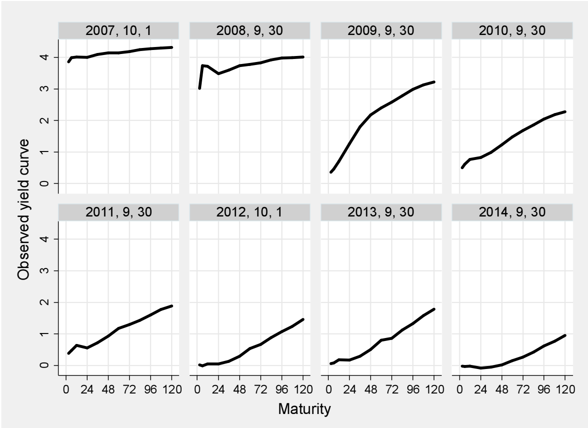
$$p_t = F(x'\beta) = \frac{e^{x_t'\beta}}{1+e^{x_t'\beta}} \quad \text{where } p_t = \Pr\left(y_t = 1 \middle| x_t'\right) \tag{5}$$

to estimate odds ratios by maximum likelihood, where the term $x_t'\beta$ includes factors and cross-country heterogeneity as explanatory variables. The former enter the estimations as changes to the Nelson-Siegel betas (3), computed as the difference between the close of business one day prior to the event and average betas over one week prior to the event (binary variable p_t). Subsequently, we compute the marginal effects of the first difference for the factors x_j

$$\frac{\partial p}{\partial x_j} = \frac{e^{x_t'\beta}}{\left(1+e^{x_t'\beta}\right)^2}\beta_j \tag{6}$$

and we report these as an increase in the probability of having observed the policy response given the subsequent changes in the shape of the yield curve. Observing both the signs and the magnitude of the marginal effects of individual factors, we are

Figure 2 Euro Area Yield Curves 2007–2014 (end of Q3) and Factors Attached to Them



Notes: The horizontal axis is in months. The betas are those estimated in (3) for the specific date displayed (end-Q3).

able to distinguish a percentage change impact of the intervention on the specific end of the yield curve (short end through the level factor, long end through the slope factor and medium-term, i.e. the closest concept to the policy-relevant horizon through the curvature). We do the same for the measure of the sovereign spread.

The predictive power of logit estimates is assessed with standard tools used to evaluate binary classification ability, the ROC (Receiver Operating Characteristic) curves[7] and the AUROC (the area under the ROC curve), which is the test that provides a single value indicating the robustness of the estimate.

4. Data

The yield curve observations used throughout this paper are sourced from Bloomberg. All yield curves in individual countries are composed of 15 different maturities ranging from three months to 30 years.[8] The euro-area composite curve is represented by the average euro-area sovereign yield weighted by GDP.

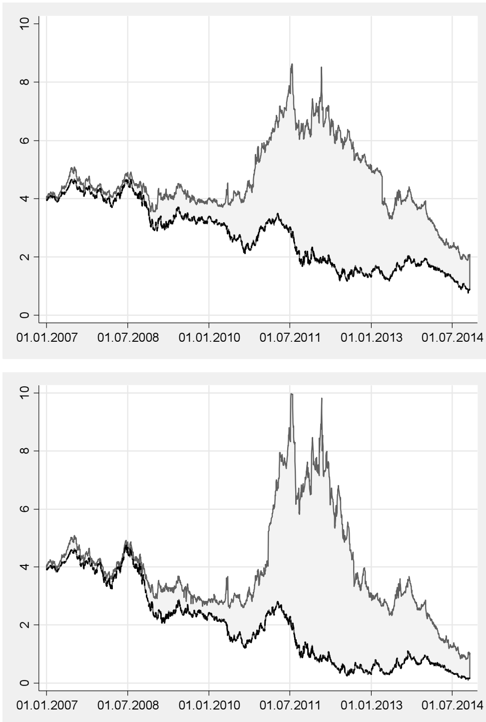
Euro-area yield curves thus constructed have been changing dynamically. In a nutshell, the flat elevated curve observed before the financial crisis (the first two segments documented in *Figure 2*) transformed into a steep upward sloping curve in 2009 (when the policy rate was cut to close to zero and markets expected a quick recovery), only to collapse further in subsequent years (segments in the lower charts) due to falling medium-term and recently also longer-term interest rate expectations.

Each pattern of the yield curve is described by the three parameters estimated from (3) and reported in *Figure 2*. Changes to these parameters are central to further analysis. The main motivation for using factor-based approximation of the yield curve is to capture the dynamics of changing interest rate expectations over the sample, especially around the events we study.

[7] See Fawcett (2004).

[8] The yield curve consists of the three-month, six-month and one-year maturities from the money market and 2-, 10-, 15-, 20- and 30-year maturities from the bond market.

Figure 3 Heterogeneity of Five-Year and Ten-Year Sovereign Yields



Note: The band above the composite yield represents 1.5-times the standard error of cross-country variation.

Geographically, some sovereign markets may be less liquid than others and therefore exhibit different properties. Further to that, changes in yields in individual countries are not linear, producing a segmented and heterogeneous environment in the euro area. Therefore, apart from changes to euro-area yield curve, policy action needs to address also this heterogeneity phenomenon. To capture this dimension, we calculate a sovereign spread in securities markets as a difference between average yields of a stressed country *vis-à-vis* German Bunds in five- and ten-year maturities (see *Figure 3*).[9]

As far as policy measures are concerned, we have identified 20 dates for each of the two types of measures that qualify to be the headline news (see *Table 1*). The qualifying conditions for the selected dates of monetary policy accommodation signals are either the top allotted volumes in longer-term refinancing operations or announcements of the most ambitious programmes by the ECB Governing Council. For the market-specific signal, conditioning is purely based on the size of secondary market purchases by volume.

The three-factor model, as designed by Diebold and Li (2006), is capable of modeling the euro-area yield curves with considerably high precision even through-

[9] Only Italy and Spain are referred to as stressed countries. Since Greece, Ireland and Portugal have been under the EC/IMF/ECB Programme for most of the observed period, including these countries would likely distort the analysis.

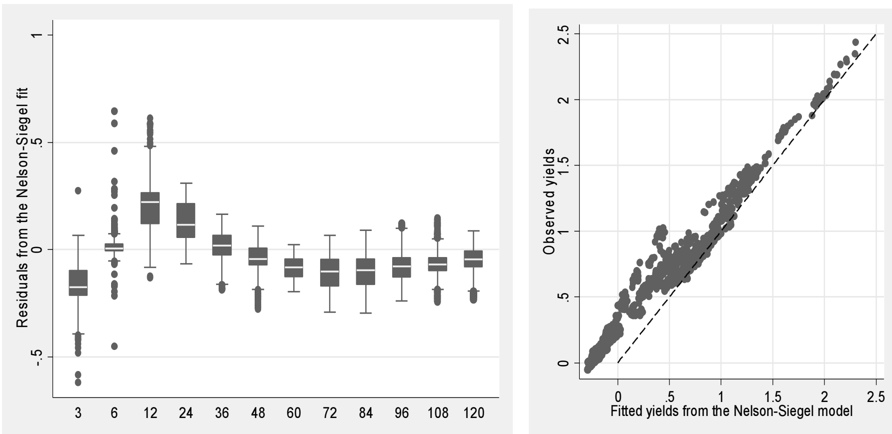
Table 1 Selected Large-Scale Daily Events

	Monetary policy accomodation signal				Market specific signal		
	Date	**Type of event**	**Event**		**Date**	**Type of event**	**Event**
1	04 IX 2008	Announcement	LTRO, 3 and 6 months	1	Date 1	Secondary market purchases	1
2	07 V 2009	Announcement	Rate cut, announcment of 1-year LTRO and SMP	2	Date 2	Secondary market purchases	2
3	24 VI 2009	1-year LTRO	allotment 442.2 bn. EUR	3	Date 3	Secondary market purchases	3
4	30 IX 2009	1-year LTRO	allotment 75.2 bn. EUR	4	Date 4	Secondary market purchases	4
5	03 XII 2009	Announcement	extension of LTROs and change to variable tenders	5	Date 5	Secondary market purchases	5
6	16 XII 2009	1-year LTRO	allotment 96.9 bn. EUR	6	Date 6	Secondary market purchases	6
7	10 VIII 2011	Liquidity, 6 months	allotment 49.8 bn. EUR	7	Date 7	Secondary market purchases	7
8	26 X 2011	1-year LTRO	allotment 56.9 bn. EUR	8	Date 8	Secondary market purchases	8
9	08 XII 2011	Announcement	3 years	9	Date 9	Secondary market purchases	9
10	14 XII 2011	Shorter liquidity	allotment 291.6 bn. EUR	10	Date 10	Secondary market purchases	10
11	21 XII 2011	3-year LTRO	allotment 489.2 bn. EUR	11	Date 11	Secondary market purchases	11
12	29 II 2012	3-year LTRO	allotment 529.5 bn. EUR	12	Date 12	Secondary market purchases	12
13	26 VII 2012	Announcement	London speech	13	Date 13	Secondary market purchases	13
14	02 VIII 2012	Announcement	OMTs	14	Date 14	Secondary market purchases	14
15	06 IX 2012	Announcement	technical framework of OMTs	15	Date 15	Secondary market purchases	15
16	04 VII 2013	Announcement	forward guidance	16	Date 16	Secondary market purchases	16
17	05 VI 2014	Announcement	further measures and negative deposit rate	17	Date 17	Secondary market purchases	17
18	03 VII 2014	Announcement	further detail of TLTROs	18	Date 18	Secondary market purchases	18
19	22 VIII 2014	Announcement	Jackson Hole - whatever it takes to counter inflation	19	Date 19	Secondary market purchases	19
20	04 IX 2014	Announcement	ABS programme and 1tn target	20	Date 20	Secondary market purchases	20

Note: In the left panel, the largest allotments and the most important announcements related to liquidity are shown; in the right panel, the set comprising the of 20 dates with the largest SMP purchases is shown.

Source: ECB.

Figure 4 Residuals of the Nelson-Siegel Model from Observed Yields



Notes: The boxplot in the left-hand panel portrays the distribution of residuals to the Nelson-Siegel fitted yield curve observations over different maturities in months. The size of the box represents the interquartile range (IQR), while the median is marked as a line subdividing the box. The lines stretch further to 1.5-times the IQR (for further explanation and justification of thresholds, see Cox (2009). The scatter plot in the right-hand panel documents the 12-month maturity in more detail. All scales are in basis points.

out the recent times of crisis. Residuals of the fitted values from (3) are displayed in the boxplot (*Figure 4*, left), documenting that fitting the observed yield curves using three factors leaves behind a residual only up to 0.1 basis point. Even the maturity with the highest mean square error (12 months) features a relatively tight fit with only a slight deviation for rates below 0.5% (*Figure 4*, right). Outcomes of Nelson-Siegel-style approximation of the euro-area yield curve make us confident that the factors are well suited for further analysis.

5. Results

We estimate equations (4a/4b) and (5) for all policy measures, then for liquidity-related measures and for SMP purchases separately. The results for dummy regressions are reported in *Tables 2* and *3*.

Given the design of factors plotted in *Figure 1*, the consequent betas estimated in (3) and anecdotally reported in *Figure 2*, it may be seen that a negative sign is attributed to betas if the level in the short run decreases, the curve slope becomes steeper on the maturity horizon and the curve becomes more kinked in the medium term.

Unconventional policy responses to adverse situations on the market are generally expected to lower the short-run yields by either explicitly pushing the policy rate lower or by supporting market liquidity conditions. Another general goal of unconventional policy measures is to help the functioning of the transmission mechanism by affecting longer-term rates more directly and thus flattening the yield curve. If unconventional measures are designed to affect primarily the medium term and fade away in the longer maturity, a more pronounced curvature should result.

The results presented in *Table 2* broadly confirm the above-mentioned characteristics, though in a differentiated manner depending on the type of policy applied.

Table 2 Regression of Shape Factors on Policy Event Date Dummies

	5-days								
	All policy responses			**Liquidity announcements**			**SMP purchases**		
	Level	*Slope*	*Curve*	*Level*	*Slope*	*Curve*	*Level*	*Slope*	*Curve*
All	-0.047***	0.007	0.028						
se	(0.018)	(0.022)	(0.050)						
LIQ				0.005	-0.054**	-0.01			
s.e.				(0.021)	(0.026)	(0.059)			
SMP							-0.168***	0.150***	0.119
s.e.							(0.033)	(0.040)	(0.090)
Observations	2031	2031	2031	2031	2031	2031	2031	2031	2031
F-test	6.81	0.11	0.33	0.06	4.23	0.03	26.66	14.12	1.72
p-value	0.0091	0.7400	0.5670	0.8080	0.0398	0.8620	0.0000	0.0002	0.1900
	1-day								
	All policy responses			**Liquidity announcements**			**SMP purchases**		
	Level	*Slope*	*Curve*	*Level*	*Slope*	*Curve*	*Level*	*Slope*	*Curve*
All	0.015	-0.017	-0.032						
s.e.	(0.010)	(0.012)	(0.031)						
LIQ				0.036***	-0.045***	-0.045			
s.e.				(0.012)	(0.014)	(0.037)			
SMP							-0.033*	0.048**	-0.003
s.e.							(0.018)	(0.022)	(0.057)
Observations	2039	2039	2039	2039	2039	2039	2039	2039	2039
F-test	2.44	1.98	1.08	9.66	9.85	1.45	3.57	4.92	0.00
p-value	0.1190	0.1600	0.2990	0.0019	0.0017	0.2290	0.0590	0.0267	0.9550

Purchases of bonds on the secondary market significantly lowered and flattened the yield curve. Given the prevailing shape of the yield curve;[10] this effect accounts for between six and twelve basis points.[11] On the other hand, we find that liquidity-related announcements affect the slope in the opposite way, i.e. they steepen the curve. However, this result is neither very robust nor very large (up to two basis points).[12]

The two different effects provide grounds for different motivations when each kind of measures is used. As the results suggest, SMP purchases were undertaken with calming the market unrest in mind (flattening the curve and suppressing heterogeneity), while liquidity-related operations were designed to stipulate activity and therefore increase interest rate expectations in the future. Given these diverging effects of the two types of measures, the cumulative effect of all policy responses

[10] The prevailing slope of the yield curve refers to the average slope in 2010–2011, when all SMP purchases were undertaken.

[11] Average slope of the yield curve (in 2010-2011) $\beta_{2,t}$ = -2.86 is multiplied by the slope loading factor ranging between 0.14 (10-year) and 0.27 (5-year) respectively and by estimated gamma 0.15. The product ranges between 6 and 12 basis points and reflects the effect on the longer side of the curve.

[12] Results with five-year sovereign yields are very similar to the ones reported in *Figure 6b*.

Table 3 Response of the Sovereign Spread to Policy Event Date Dummies

Sovereign spread	5-days						1-day					
	All policies		Liquidity related		SMP		All policies		Liquidity related		SMP	
	5-year	10-year	5-year	10-year	5-year	10-year	5-year	10-year	5-year	10-year	5-year	10-year
All	0.036	0.033					-0.031**	-0.032**				
s.e.	(0.028)	(0.023)					(0.016)	(0.013)				
LIQ			-0.046	-0.033					-0.064***	-0.062***		
s.e.			(0.034)	(0.028)					(0.019)	(0.016)		
SMP					0.226***	0.187***					0.047	0.036
s.e.					(0.051)	(0.042)					(0.029)	(0.025)
Observations	2032	2032	2032	2032	2032	2032	2040	2040	2040	2040	2040	2040
F-test	1.61	2.00	1.82	1.39	19.34	19.38	3.88	5.77	11.73	14.76	2.64	2.16
p-value	0.2050	0.1580	0.1770	0.2380	0.0000	0.0000	0.0489	0.0164	0.0006	0.0001	0.1050	0.1420

Table 4 Predictability of Policy Response

	All policy responses				Liquidity announcements				SMP purchases			
	Level	*Slope*	*Curve*	*Joined*	*Level*	*Slope*	*Curve*	*Joined*	*Level*	*Slope*	*Curve*	*Joined*
Joined ME	0.137***	-0,004	0,043	0.271***	0.061*	0,028	0.030**	0.124***	0.0508***	-0,027	0,008	0.070**
s.e.	(0.038)	(0.041)	(0.027)	(0.057)	(0.035)	(0.025)	(0.015)	(0.043)	(0.018)	(0.019)	(0.027)	(0.030)
5-year spread ME	0.046**	0.044**	0.035	0.042**	0.034**	0.032**	0.031**	0.032***	0.009	0.010	0.001	0.007
s.e.	(0.019)	(0.022)	(0.023)	(0.016)	(0.013)	(0.013)	(0.013)	(0.012)	(0.011)	(0.016)	(0.025)	(0.005)
Level ME	0.091**			0.153***	0.027			0.056**	0.042***			0.047***
s.e.	(0.037)			(0.038)	(0.030)			(0.026)	(0.012)			(0.017)
Slope ME		-0.049		0.050**		-0.004		0.029		-0.036***		0.008
s.e.		(0.035)		(0.021)		(0.025)		(0.019)		(0.012)		(0.006)
Curve ME			0.008	0.026***			-0.001	0.006			0.007**	0.009**
s.e.			(0.008)	(0.008)			(0.006)	(0.006)			(0.003)	(0.004)
Observations	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035
Overall F-test	10.40	3.54	1.29	26.52	3.61	2.12	2.32	8.42	20.35	10.25	7.11	37.44
p-value	(0.006)	(0.170)	(0.524)	(0.000)	(0.165)	(0.347)	(0.314)	(0.077)	(0.000)	(0.006)	(0.029)	(0.000)
Loglikelihood	-191.4	-194.4	-195.3	-188.6	-146	-146.4	-146.4	-145.5	-66.37	-69.43	-72.44	-61.35
AUROC	0.620	0.532	0.516	0.663	0.549	0.523	0.521	0.572	0.750	0.716	0.636	0.808
seroc	(0.052)	(0.054)	(0.060)	(0.048)	(0.060)	(0.065)	(0.063)	(0.060)	(0.078)	(0.079)	(0.093)	(0.070)

yields non-significant results. The only exception is a very slight effect (five basis points) in the short run.

The split between the two types of measures is also confirmed by the results from (4b) and reported in *Table 3*. While we may observe an immediate response of the sovereign spread to liquidity-based measures (by six basis points), no such effect has been found for the secondary market purchases. Moreover, while for the former this effect fades away in several days, sovereign spreads even widen in the days following the intervention. As striking as the irrelevance of the secondary market purchase programme to bond market fluctuation may seem, it perfectly aligns with the existing literature.[13]

We have found that a policy signal advances the shape of the yield curve and it does so subject to the type of measure. An asymmetric response to the unconventional measures suggests that the response of the monetary authority also differs with regard to the market situation. We test this by reversing the link, i.e. investigating whether the policy response could have been predicted by a modified slope of the yield curve. To do this, we employ the logit regression defined in (5) and report the marginal effects in *Table 4*.

These effects convey that short-run unfavourable changes to both cross-country heterogeneity and the shape of the yield curve do increase the probability of policy responses. As documented in *Table 4*, the increased probability of policy action following overall deterioration in interest rate expectations turns out to be quite significant. Complementary to our earlier finding that the yield curve responds to secondary market purchases, changes to the shape of the yield curve also conversely carry some prior information about the policy response of the purchases (although primarily for the short end). Although this is not the case for liquidity-based policy measures, these may be better predicted by deterioration in the sovereign spreads of periphery countries.

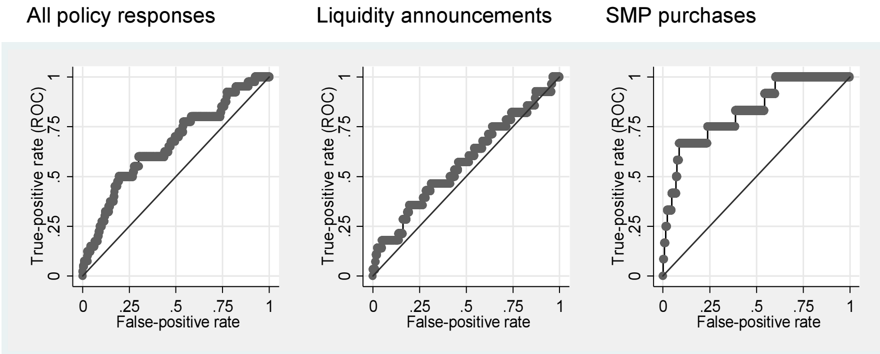
Taking all yield curve shape factors and the heterogeneity of sovereigns together, we find that as a result of deteriorating market conditions, the probability of adopting liquidity-based measures increases by 12% and of a large SMP purchase by 7%.

Although we find higher and more significant coefficients when all policy responses are taken into account, these results are not as conclusive as the ones related to secondary market purchases. This conclusion may be drawn from the overall predictive power of the model given by the standard tool to evaluate binary classification ability, the Receiver Operating Characteristics (ROC) analysis.[14] This is shown in *Figure 5* for the baseline Logit model.

[13] Ghysels *et al.* (2014) confirm that SMP successfully reduced the yields and volatility of government bonds; however, the duration of the effect was identified as lasting only several hours and vanishing thereafter.

[14] The curve plots the true positive rate (TP) on the horizontal axis versus the false positive rate (FP) on the vertical axis for all possible thresholds of the binary classifier. When the threshold gets large and negative, the classifier is calling the signal strongly; almost all signals will appear above the threshold and both TP and FP converge to one (top right corner). On the other hand, if the threshold gets large and positive, the classifier will be very conservative in spotting the signal; almost all signals are below the threshold and both TP and FP will converge to zero (bottom left corner). For all the other positions on the schedule, the informative classifier should deliver TP > FP, so the ROC curve should appear above a 45-degree line that relates to an uninformed signal call, often also referred to as a coin toss.

Figure 5 Area under the ROC Curve



The test of predictive ability of the model based on this analysis is provided by comparing the distribution of the model signals to the uninformed classifier, i.e. calculating the area under the ROC curve (AUROC). The type 2 signal of the model with secondary market purchases with AUROC = 0.81 is impressive, while AUROC of 0.66 for the type 1 signal may still be treated as quite informative.

We have performed several robustness checks to uphold the analysis. First of all, the baseline omits the very long end of the yield curve (sovereign debt maturing in more than ten years), as this is usually less liquid and often not present in smaller markets. To account for full, complete yield curves, we have run both exercises on a full curve dataset up to 30 years maturity. Second, since sovereign debt yields may capture some country specific noise, we alternated the euro-area synthetic yield curve with an overnight index swap curve. Both consistency checks produced a broadly similar picture for the short- and medium-term results in the baseline (see *Appendix*), suggesting that from this perspective the results may be considered robust.

6. Conclusion

We have confirmed that policy action involving secondary market purchases is followed by immediate changes to the shape of the euro-area yield curve. The overall yield curve has been found to shift downward and flatten following this type of policy action. On top of the measurable *ex-post* market response, the policy response itself may be predicted by short-run changes in the shape of the yield curve observed *prior* to the policy action.

As much as this phenomenon is found present for the largest secondary market purchases, it has not been confirmed for the main monetary policy events related to the extension of central bank liquidity. The slope and curvature of the yield curve have been found to be only mildly affected, which may be explained by the more strategic nature of the latter type of unconventional policy action. Moreover, given their focus on stimulation rather than on calming segmented and malfunctioning markets, the effect of liquidity-related measures has been found to be broadly inverse to those of secondary market purchases. Nevertheless, this effect has been found to fade away rather quickly.

The different natures of the two types of measures have also been confirmed by the effects on the sovereign spread of stressed euro-area countries. We observe an immediate contraction of six basis points in spreads in response to liquidity-based measures, with a rather quick correction thereafter. On the other hand, in terms of the effects on sovereign spreads, the largest secondary market purchases are found to be widely irrelevant.

Divergence between the two types of measures holds also for the prior predictive characteristics of the sovereign spreads and the factors of the yield curve pattern. While movements of spreads seem to be significant for identifying liquidity-based measures, it is more the pattern of the yield curve that identifies the largest secondary market purchases. However, a test of predictive power strongly confirms primarily the predictability of secondary market purchases, while the predictability of pooled events passes the test by only a tiny margin.

Overall, we have succeeded in addressing the three main questions. First, the nature of unconventional monetary policy action has different consequences for *ex-post* shifts in future interest rate expectations. While secondary market purchases compress yields and flatten the curve, measures and announcements related to central bank liquidity propagate a steeper and more kinked yield curve and compress the sovereign spreads of stressed countries albeit although for a very limited period. Second, sovereign debt purchases are to some extent predictable from *ex-ante* changes to the pattern of the yield curve, while measures related to extension of central bank liquidity are rather more predictable from widened sovereign spreads. Third, the Nelson-Siegel type of term structure functional approximation proves helpful for a quantitative assessment of yield curve dynamics. Especially helpful is the reflection of the changes in the curve level, slope and curvature in maturity terms vis-à-vis policy surprises.

The first two findings in general suggest that ex-post effects of unconventional policy measures, their direction and partial predictability are in line with their underlying strategy and design by the monetary authority.

APPENDIX

Table A1 Predictability of Policy Response (with Full Set of Maturities)

	All policy responses				Liquidity announcements				SMP purchases			
	Level	*Slope*	*Curve*	*Joined*	*Level*	*Slope*	*Curve*	*Joined*	*Level*	*Slope*	*Curve*	*Joined*
Joined ME	0.137***	-0.002	0.053**	0.272***	0.070*	0.027	0.030*	0.122***	0.052***	-0.026	0.013	0.073**
s.e.	(0.043)	(0.042)	(0.025)	(0.058)	(0.039)	(0.027)	(0.016)	(0.042)	(0.019)	(0.023)	(0.021)	(0.029)
5-year spread ME	0.043**	0.043**	0.036*	0.040**	0.034**	0.032**	0.031***	0.032***	0.007	0.008	0.002	0.006
s.e.	(0.020)	(0.022)	(0.022)	(0.017)	(0.012)	(0.013)	(0.013)	(0.012)	(0.014)	(0.019)	(0.020)	(0.005)
Level ME	0.094			0.149	0.036			0.059**	0.045			0.046***
s.e.	(0.043)			(0.041)	(0.036)			(0.028)	(0.015)			(0.016)
Slope ME		-0.045		0.053		-0.005		0.027		-0.035***		0.010
s.e.		(0.037)		(0.024)		(0.027)		(0.020)		(0.013)		(0.008)
Curve ME			0.017**	0.030			-0.002	0.005			0.011***	0.011**
s.e.			(0.009)	(0.009)			(0.006)	(0.006)			(0.004)	(0.005)
Observations	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035
Overall F-test	10.91	4.40	4.76	28.61	7.30	5.29	5.31	11.39	12.95	6.51	18.43	39.03
p-value	(0.004)	(0.111)	(0.093)	(0.000)	(0.026)	(0.071)	(0.070)	(0.023)	(0.002)	(0.039)	(0.000)	(0.000)
Loglikelihood	-191.4	-193.8	-193.6	-188.0	-144.5	-145.1	-145.1	-144.1	-69.57	-71.05	-69.89	-62.58
AUROC	0.621	0.558	0.556	0.679	0.581	0.586	0.576	0.604	0.663	0.648	0.768	0.824
seroc	(0.051)	(0.056)	(0.057)	(0.044)	(0.058)	(0.062)	(0.063)	(0.057)	(0.096)	(0.084)	(0.082)	(0.059)

Table A2 Predictability of Policy Response (with OIS)

	All policy responses				Liquidity announcements				SMP purchases			
	Level	*Slope*	*Curve*	*Joined*	*Level*	*Slope*	*Curve*	*Joined*	*Level*	*Slope*	*Curve*	*Joined*
Joined ME	0.126***	0.016	0.051**	0.355***	0.0682**	0.015	0.034**	0.139**	0.041*	-0.003	0.013	0.108***
s.e.	(0.038)	(0.042)	(0.025)	(0.075)	(0.031)	(0.029)	(0.015)	(0.060)	(0.028)	(0.034)	(0.023)	(0.036)
5-year spread ME	0.043	0.038	0.033	0.033**	0.034***	0.033***	0.030***	0.032***	0.006	0.001	0.001	0.002
s.e.	(0.021)	(0.024)	(0.023)	(0.018)	(0.012)	(0.013)	(0.013)	(0.011)	(0.022)	(0.030)	(0.022)	(0.007)
Level ME	0.083			0.188***	0.034			0.068**	0.036***			0.062***
s.e.	(0.032)			(0.044)	(0.027)			(0.034)	(0.014)			(0.019)
Slope ME		-0.022		0.104***		-0.018		0.032		-0.003		0.032***
s.e.		(0.037)		(0.031)		(0.027)		(0.027)		(0.025)		(0.013)
Curve ME			0.019	0.030***			0.004	0.008			0.012***	0.013***
s.e.			(0.010)	(0.009)			(0.007)	(0.006)			(0.005)	(0.004)
Observations	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035	2035
Overall F-test	9.66	2.23	4.96	33.14	7.92	6.42	5.12	11.23	7.68	0.02	8.05	47.56
p-value	(0.008)	(0.329)	(0.084)	(0.000)	(0.019)	(0.040)	(0.077)	(0.024)	(0.022)	(0.991)	(0.018)	(0.000)
Loglikelihood	-191.8	-194.6	-193.8	-186.5	-144.5	-144.9	-145.1	-144	-70.57	-73.55	-71.78	-62.77
AUROC	0.597	0.548	0.565	0.691	0.585	0.577	0.582	0.609	0.645	0.473	0.686	0.841
seroc	(0.053)	(0.057)	(0.057)	(0.040)	(0.055)	(0.060)	(0.063)	(0.053)	(0.105)	(0.101)	(0.086)	(0.057)

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