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(Working Papers)

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THE NON-LINEAR EFFECTS OF THE FED’S ASSET PURCHASES

by Alessio Anzuini*

Abstract

The Federal Reserve responded to the global financial crisis of 2008 with the deployment of new monetary policy tools, the most notable of them being the expansion of its balance sheet. In a recent paper, Weale and Wiladeck (2016) show that the asset purchases were effective in stimulating economic activity, inflation and asset prices. In this paper, we show that the results of asset purchases are state-dependent: large scale purchases are effective only when financial markets are impaired. Using an estimated threshold vector autoregressive model conditional on the volatility regime, we show that an increase in the balance sheet has expansionary effects on GPD and inflation when volatility is high, but not when it is low (in which case its effects become mostly insignificant). We argue that high volatility can be interpreted as a proxy of market dysfunction, and therefore only when this transmission channel is active is unconventional monetary policy particularly effective. This suggest that models of transmission mechanisms of unconventional policies that are based on asset purchases should focus more on the market functioning channel and not only on the portfolio rebalance channel.

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1 Introduction

After the Global financial crisis (GFC), with interest rates at the zero lower bound (ZLB), major central banks embarked in large-scale asset purchases (LSAPs) to provide monetary stimulus to the economy. Weale and Wieladeck (2016; WW hereafter) have shown that LSAPs in the United States were effective in stimulating economic activity and inflation, via a number of channels: a decrease in the term premium component of longer maturities bonds (portfolio balance-effect); an enhancement of market functioning, due to the presence a large buyer playing the role of market maker and liquidity provider in a period of significant market stress; a boost to risky asset price prompting a positive wealth effect. Indeed, the most visible impact of LSAP is a decrease in long term interest rates and an increase of risky asset prices (we also document a decline of asset price volatility). All these effects are at work in WW, who estimate VAR models identified, in the baseline version, with a Cholesky decomposition, and find that a one-percent of GDP-equivalent increase in asset purchases induces a decline of long term interest rates, an increase of asset prices and in both economic activity and inflation. We show that the effects recovered in WW using a linear model, disappear conditioning on some states of the economy. Our conjecture is that LSAP expansionary effects on the economy are strongly dependent on the existence of stress in financial markets so that market functioning channel is at work. We identify this channel through volatility: market dis-functioning (normal functioning) are associated with high (low) level of implied volatility in the stock market (VIX). Conditioning on different volatility level, we do find differences in the responses of economic variables: when volatility is high, a balance sheet expansion effectively boosts economic activity and prices through the channels described above. However, when volatility is low, none of those effects materializes, i.e. balance sheet expansion is ineffective as a way to steer the economy. The economic intuition is straightforward (and not new) once we interpret exceptionally high volatility as a sign of market distress: non-conventional policies are effective when markets impaired channel is at work (see Gagnon et al. (2001) and Curdia and Woodford (2011). Moreover, we show that our results are robust to different proxies of market dis-functioning.

In order to recover these non-linear effects, we estimate a threshold vector autoregressive (TVAR) model using the same variables as in WW. The VIX is our threshold variable, and we test for the presence of non-linearities conditional on the volatility regime; we are then able to recover standard linear impulse response functions, conditioning on the volatility regime and using bayesian techniques to mitigate the small

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1I would like to thank Piergiorgio Alessandri, Giuseppe Ferrero, Marcello Pericoli and two anonymous referees for their suggestions. All errors are solely mine. The opinions expressed herein are of the author and do not necessarily reflect those of Banca d’Italia.

2See Boecckx et al (2017) and Gambacorta et al. (2014) for similar results within the euro area and Lewis and Roth (2017) for a discussion of medium run effects of balance sheet policies on financial stability.
sample bias. We show that the effects of balance sheet policies are significant, and have the expected sign, only in the high volatility regime: following an increase in the asset purchase equivalent to a 1 per cent of GDP, long term rates decline and asset prices, GDP and inflation all increase. None of those effects survive in the low volatility regime.

The uncovered non-linearity has far reaching implications. On the one hand since all past recessions have been accompanied by a shift to a high volatility regime our estimates suggest that unconventional policies will regain effectiveness exactly when they are needed. On the other hand, if volatility remain low and, most importantly, the market dis-function channel is not at work, it is unclear how effective the LSAP could be.

In the next section we first describe the baseline results of WW and then we introduce the TVAR methodology. In section 3 we apply the TVAR methodology the Fed unconventional monetary policy. Section 4 describes the main results and section 5 provides robustness analysis. Section 6 concludes.

2 Linear VAR vs TVAR

In their contribution WW estimate a set of vector autoregressive (VAR) models identified with a Cholesky decomposition. They use monthly data from March 2009 to May 2014, a sample encompassing only a period when asset purchases were an active policy tool. The variables included in the VAR, ordered in the Cholesky decomposition as follows, are: real GDP, CPI, asset purchases as a percentage of GDP, the ten year government bond yield, and real equity prices (deflated using the CPI); all variables are in log levels (except those expressed in percentage point). Asset purchases are measured as the whole amount of planned purchases, for each program or change to a previous program, at the date when they were announced by the Fed; the maturity extension program (Operation Twist, OT) is an additional data point, as the asset purchase announcements of government bonds financed with the issuance of central bank reserves.

In WW, averaging across the various identification schemes, GDP peaks at 0.58% and CPI at 0.62%, similarly to the results in Baumeister and Benati (2013) and Kapetanios

3Normalized by the first quarter of 2009.
4Hesse et al (2017) argue that subsequent round of QE were less effective in the US because they were partly anticipated.
5The WW model implicitly assumes that macroeconomic variables tend to respond to announcements, rather than actual asset purchases. However, they find that results are robust to using an alternative specification where the actual amount of assets purchased in each period is used instead. Also the treatment of the Operation Twist as if it were an announcement of purchases is debatable. For example in September 2011 the FOMC announced that: "The Committee intends to purchase, by the end of June 2012, $400 billion of Treasury securities with remaining maturities of 6 years to 30 years and to sell an equal amount of Treasury securities with remaining maturities of 3 years or less." This announcement translated directly into an increase of $400 billion in the series used in our estimates. While this may overestimate the series of asset purchase, WW show nonetheless that by rescaling by a half all the OT their results did not change. Please refer to the original paper for an in-depth explanation of the construction of the variables.
et al. (2012).  

The use of a linear model in WW implies a sort of symmetry in the response to a shock: what occurs in the balance sheet expansion phase should be the mirror image of what happens in the unwinding phase, however slowly it is implemented. Surprisingly, though, while balance sheet normalization was announced in early 2017 and actually started in October, it produced no perceptible impact on financial markets. We surmise (and want to test the hypothesis) that the absence of contractionary effects during this phase is not due to a simple asymmetry in the effects of expansion and contraction in balance sheet but rather to a non-linearity stemming from the state of the financial markets: if markets are calm and volatility is low, then balance sheet increases (decreases) have no expansionary (contractionary) effects; when, instead, financial markets are under pressure and volatility is high, those effects are significant and in line with what found in WW.

This intuition is not completely new. As already argued by Gagnon et al. (2011), the LSAPs may affect market interest rates mostly through a combination of portfolio balance and market functioning effects. The lack of significant movements of interest rates around the times each component of the LSAP programs was wound down suggests that market functioning was no longer impaired, and that the Fed’s presence in the market had little additional effect beyond that through its portfolio holdings.

In line with Curdia and Woodford (2011), we find a much greater role for financial market stress (proxied by high or low volatility) in explaining the impact of unconventional policy than in Gagnon et al. (2011). To the best of our knowledge, in this paper we provide the first VAR analysis of the effects of unconventional monetary policy conditional on changing regimes.

2.1 The TVAR methodology

Using a threshold VAR we show that WW results can be interpreted as an across-regime estimates and that, since they do not explicitly deal with non-linearity, they may be strongly biased. We use the very same variables as in WW, except that we add the S&P500 implied volatility index (VIX) to our threshold vector autoregressive model (TVAR).

TVAR models have been applied in economics to examine the relationship between savings, openness and growth (Hoogstrate and Osang, 2005), between carry trade and foreign exchange rate volatility (Anzuini and Brusa, 2016), and in finance, for instance in the study of index futures arbitrage (Tsai, 1998). In this paper, a TVAR model is adopted to examine the relationship between balance sheet policies and market functioning. Our idea is that the impact of unconventional policies on financial markets and economic activity is asymmetric: much stronger in a distressed market, almost ininfluential in tranquil times when volatility is low. In our analysis the degree of market distress is proxied by the VIX, although we acknowledge that also other variables may be used

6In WW results obtained using sign restriction are bigger than those obtained with the Cholesky, however, due to the large uncertainty surrounding point estimates, these results are not statistically different from one another.
to gauge the level of market malfunctioning; we will show, however, that using other
variables do not change the main results.

The empirical strategy follows Tsay (1998), who addresses both testing and model
building issues concerning implementation of the TVAR technique. The TVAR spec-
ification he proposes is a multivariate version of the Self-Exciting Threshold Models
outlined by Tong (1990). The peculiarity of the Threshold models in general is the use
of a threshold variable to capture non-linearities. Within this group, TVAR models and
Self-Exciting Threshold Models have two distinctive features: (i) they are linear autore-
gressive processes within each regime and (ii) they employ a delayed threshold variable
to govern regime switching. Indeed, in a TVAR model the regime in place at any time
t depends on the observable past history of the threshold variable itself.

A s-regime TVAR model, also called a Multivariate Threshold Model, satisfies (Tsay,
1998):

\[ y_t = c_j + \sum_{i=1}^{p} \Phi^{(j)}_i y_{t-i} + \sum_{i=1}^{q} \beta^{(j)}_i x_{t-i} + \epsilon_t^{(j)} \] 
\[ \text{if } \gamma_{j-1} < b_{t-d} \leq \gamma_j \]  

where \( y_t \) is a vector of endogenous variables, \( j = 1, \ldots, s \) indicates the regime/s, \( c_j \) are
the constant vectors for the different regimes, \( \Phi^{(j)}_i \) denotes the coefficient matrix of the
respective lags and regime, \( \gamma_{j-1} \) and \( \gamma_j \) are threshold values and \( p \) is the number of lags
included. The delayed threshold variable, \( b_{t-d} \), determines which regime the system is
in at any time. Asymmetries arise, as the coefficients of the linear VAR model can vary
across the regimes defined by \( b_{t-d} \), where \( d \) denotes the delay integer. Crucially, the
model in (1) allows for an endogenous threshold variable, which can be defined as one of
the endogenous variables in the model (as in our case) or alternatively can be computed
as a function of one of them. Since the VIX is used as threshold variable, the thresh-
hold level of volatility that induces parameter shifts is endogenous to the econometric
procedure (derived via grid searches, details below) rather than exogenously imposed.
Furthermore, since shocks to any element in \( y_t \) are potentially able to induce a regime-
shift via the threshold variable itself, regime switches are themselves endogenous in the
model. Concerning the statistical properties, the threshold variable \( b_t \) is required to be
stationary and to have a continuous distribution. The model in (1) is specified in the
general form: it allows for \( s \) regimes, such that \( -\infty = \gamma_0 < \gamma_1 < \ldots < \gamma_s < +\infty \) and
is defined for a given vector of the exogenous variables, \( x_t \) with lag order \( q \). Since the
benchmark (linear) WW model does not include any exogenous variable, \( x_t \) is a vector
of zeros in this study. Finally, the \( \epsilon_t^{(j)} \) are sequences of white noises and are mutually
independent.

Before modeling the TVAR specification, the presence of threshold non-linearity is
formally assessed (using the Tsay test).

Testing the validity of a TVAR model (i.e. a linear VAR model under the null
hypothesis and TVAR model under the alternative) involves non-standard inference due
to the so called “nuisance parameter” problem: when threshold values are unknown,
the parameters \( \gamma_{j=1,\ldots,s} \) in (1) are identified under the alternative, but not under the
null. In this study, the ad hoc test statistic designed by Tsay (1998) is employed to
conduct inference. Tsay (1998) transforms the problem of testing for a threshold into a problem of testing for a change-point. The model in (1) is re-arranged according to the increasing order of the threshold variable \(b_t - d\); predictive residuals are then obtained in the new setup via recursive least squares and are used to construct a test statistic that does not involve undefined parameters. The Tsay test statistic has an asymptotic Chi-squared distribution and can be also specified to allow for conditional heteroscedasticity.

To assess the stability of the results, the Tsay test is generally performed for different starting values of the recursive estimation, \(m_0\). The test is designed to jointly detect the appropriate delay parameter \(d\) and the presence of non-linearity and assumes that both the threshold variable \(b_t\) and the lag parameter \(p\) are known. A standard procedure is to select the order \(p\) in the linear framework using an Information Criterion (i.e. AIC, HQ or SIB).

Modelling a TVAR model includes selecting the threshold variable \(b_t\), determining the number of regimes \(s\), and choosing the order \(p\) for each regime (Tsay, 1998). A TVAR model is estimated by using the conditional least square method, while the selection of the best TVAR specification is based on some information criteria (i.e. commonly the minimum Akaike Information Criterion or the sum of squares residuals). The threshold values \(\gamma_j = 1, \ldots, s\) are determined according to a grid search over a range of potential values of the threshold variable. Given \(s, p\) and the threshold variable \(b_t\) and conditional on each of these potential values, the TVAR model is estimated by ordinary least squares. The best TVAR specification is then selected using the aforementioned method. To ensure that each regime contains a minimum number of observations, the grid is usually restricted. It is common practice in the literature to allow for at least 10 percent of the total number of observations in each regime (Tsay, 1998; Hansen, 2000; Clements and Galvao, 2004). In our case, however, due to the very small sample size, we decide to leave at least 25 percent of observations in each regime and the number of possible regime is restricted to two. Once the best TVAR model has been selected, the specification is refined choosing the appropriate number of lags \(p\) in each regime; again, due to lack of available observation we use only one lag in each regime.

Finally, we estimate a set of conditional linear impulse responses to assess whether the dynamics of macro variables differ across the volatility regimes defined by the estimated TVAR model. Since conditional linear impulse responses are regime-dependent, they describe the dynamics of the system within each of the regimes identified by the estimated threshold values. There is indeed a limiting assumption underlying this approach: the regime prevailing at the time of the shock is supposed to be preserved throughout the horizon of the responses (Balke, 2000). It follows that conditional impulse responses are

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8Refer to Tsay (2008) for a formal and detailed description of the Test.

9Tsay (1998) studies the finite-sample performance of this test by simulation and recommends choosing \(m_0 \sim 5\sqrt{n}\) when \(y_t\) is a unit root series, and \(m_0 \sim 3\sqrt{n}\) under stationarity, where \(n\) is the sample size. The choice is a compromise between stable starting estimation and good power in testing.

10The choice of an appropriate threshold variable requires a careful investigation and remains one of the major problems in empirical applications of the method (Tsay, 1998).
an appropriate tool for examining the responses to an analogous shock in the presence of alternative volatility states, but are not designed to capture regime switching during the propagation of the shock.\textsuperscript{11}

2.2 Data

We estimate our TVAR model with monthly data from 2009m3 to 2017m5: in March 2009 asset purchases began to be an active policy and May 2017 is the last month before the Federal reserve announced it was start removing the balance sheet stimulus. At the June 2017 FOMC meeting the Fed published an Addendum to the Policy Normalization Principles and Plans, stating that: "The Committee intends to gradually reduce the Federal Reserve’s securities holdings by decreasing its reinvestment of the principal payments it receives from securities held in the System Open Market Account." It also specified the pace at which the removal was about to take place, but not the end-point at which balance sheet reduction would stop. This made it impossible for markets to telescope into the present the value of the overall balance sheet contraction, and very hard for an econometrician to incorporate this information into the construction of the series of the asset purchases for the estimates. However, FOMC members suggested, in public speeches, that balance sheet reduction was bound to halt somewhere in between the current level and the one prevailing before asset purchases began (1tn$).\textsuperscript{12}

Monthly real GDP data for the US are taken from Macroeconomic Advisers. Consumer prices are the official measures published by the Bureau of Labour Statistics. Real equity prices are calculated by obtaining monthly averages of daily data for the S&P500 obtained from Thomson Datastream and deflating with the CPI. The asset purchases series is constructed following WW.\textsuperscript{13}

3 The TVAR Model of LSAP

The relationship between LSAP and the volatility level, to the best of our knowledge, has never been directly investigated before. There is, however, widespread consensus that LSAP effectiveness tends to be more pronounced when implemented in times of market distress (see among other Gagnon et al. (2011) and Curdia and Woodford (2011)).

We use volatility as a threshold variable and, while we do acknowledge the possibility that other proxies for market dysfunctions may work as well, we choose VIX for at least two reasons: 1) it is possibly the best known index of market sentiment, 2) it is correlated with a lot of other series that might be used as a threshold variable.\textsuperscript{14}

\textsuperscript{11} Notice that this caveat is well known in the literature and no clear solution has emerged.

\textsuperscript{12} On November 28 2018 the Fed Chair Designate Powell said, during his confirmation hearing before the Senate Committee on Banking, Housing, and Urban Affairs, that he sees the balance sheet ending up around $2.5 trillion to $3 trillion.

\textsuperscript{13} The series is expressed in percentage of annualised 2009Q1 nominal GDP in order to avoid the endogeneity issues which might arise from scaling by current nominal GDP.

\textsuperscript{14} For example, the correlation between the convenience yield (i.e. the yield spread between a completely illiquid and a comparable fully liquid security) and the VIX is almost 0.9. For the convenience
robustness section we test the presence of non-linearities and estimate the parameters in the different states using three other possible threshold that usually indicate dysfunctions in the markets liable to affect the monetary policy transmission mechanism.

In order to argue that we should expect a stronger impact of LSAP in presence of market dysfunctions, it is worth mentioning the channels through which this policy affects the broad economy. For an in depth analysis of channels through which LSAP affects the economy see Krishnamurthy et al. (2011), in what follows we draw heavily on Gagnon et al. (2011).

The primary channel through which LSAPs appear to work is by affecting the risk premium on the asset being purchased. By purchasing a particular asset, a central bank reduces the amount of the security that the private sector holds, displacing some investors and reducing the holdings of others, while simultaneously increasing the amount of short-term, risk-free bank reserves held by the private sector. In order for investors to be willing to make those adjustments, the expected return on the purchased security has to fall. Put differently, the purchases bid up the price of the asset and hence lower its yield. This pattern was described by Tobin (1958, 1969) and is commonly known as the “portfolio balance” effect. Note that the portfolio balance effect has nothing to do with the expected path of short-term interest rates. Longer-term yields can be parsed into two components: the average level of short-term risk-free interest rates expected to prevail over the term to maturity of the asset and a risk premium (the term premium). The former represents the expected return that investors could earn by rolling over short-term risk-free investments, and the latter is the expected additional return that investors demand for holding the risk associated with the longer-term asset. In theory, the effects of the LSAPs on longer-term interest rates could arise by influencing either of these two components. However, the Federal Reserve did not use LSAPs as an explicit signal that the future path of short-term risk-free interest rates would remain low.

These portfolio balance effects should not only reduce longer-term yields on the assets being purchased but should also spill over into the yields on other assets. The reason is that investors view different assets as substitutes and, in response to changes in the relative rates of return, will attempt to buy more of the assets with higher relative returns. In this case, lower prospective returns on agency debt, agency MBS, and Treasury securities should cause investors to seek to shift some of their portfolios into other assets such as corporate bonds and equities and thus should bid up their prices. It is through the broad array of all asset prices that the LSAPs would be expected to provide stimulus to economic activity.

The LSAP programs began at a point of significant market strains, and the poor liquidity of some assets weighed on their prices. By providing an ongoing source of demand for longer-term assets, the LSAPs may have allowed dealers and other investors to take larger positions in these securities or to act as market-makers in them, knowing that, if needed, they could always sell the assets to the Federal Reserve.

Such improved trading opportunities could also reduce the liquidity risk premiums yield we used the series constructed in Del Negro et al. (2017); data are available only to the end of 2014.
embedded in asset prices, thereby lowering their yields. This liquidity, or market functioning, channel, which is distinct from the portfolio balance channel, appears to have been important in the early stages of the LSAP programs for certain types of assets.

For example, the LSAP programs began at a point when the spreads between yields on agency-related securities and on Treasury securities were well above historical norms, even after adjusting for the convexity risk in MBS associated with the high interest rate volatility at the time. These spreads reflected in part poor liquidity and elevated liquidity risk premia on these securities. The flow of Federal Reserve purchases may have helped to restore liquidity in these markets and reduced the liquidity risk of holding those securities, thereby narrowing their spreads.

Overall, LSAPs may affect market interest rates through a combination of portfolio balance and market functioning effects.

As documented in Gagnon et al. (2011), the lack of significant movements in interest rates around the times that each component of the LSAP programs was wound down suggests that market functioning was no longer impaired and that the Federal Reserve’s presence in the market had little additional effect beyond that through its portfolio holdings. More explicitly, our estimates will show that once the market functioning channel is shut down, the impact of LSAP is greatly reduced, up to a point where its impact on the broad economy becomes difficult to disentangle. In order to interpret the different response in the two regimes as due to the switching of the market functioning channel, one more implicit identifying assumption is needed: once the VIX is below a certain threshold, the market functioning channel is shut down. While the choice of the VIX as a threshold is based on our prior information, the actual value of the threshold used in our TVAR model is obtained through econometric tests. One thing is worth stressing: our analysis (and the one from WW) is constrained by the lack of observations. Obviously, we would have preferred to leave unconstrained the number of regimes but the lack of available observation forced us to impose the existence of only two regimes.\footnote{The possibility of more than two regimes would have allowed us to relax the, rather stringent, identifying assumption that market functioning channel is on (off) simply when volatility is above (below) the threshold. Three regimes for example would have allowed to assume the market functioning channel to be completely switched off (on) only in the very low (high) volatility regime leaving the middle regime unconstrained.}

3.1 Testing a TVAR model: Tsay test

Testing for threshold effects (i.e. with the Tsay test) entails selecting the lag parameter $p$ and choosing a threshold variable $b_t$.

To select $p$, the number of lags, we employ the Multivariate Akaike Information Criterion (MAIC)\footnote{MAIC = $n \log |\hat{\Sigma}| + 2(k^2 p + k)$ where $\hat{\Sigma}$ is the variance-covariance matrix of residuals, $n$ is the number of observations, $p$ is the number of lags and $k$ is the number of endogenous variables. Once the threshold value is determined and we proceed with the estimates in the different regimes, due to the lack of degrees of freedom we are forced to reduce the number of lags to one.}.
The choice of the threshold variable requires careful evaluation: a misspecification may invalidate the selection of the regimes, thus affecting the ultimate conclusions of the analysis. As anticipated, in our baseline estimates, we capture non-linearities using the VIX, which is both endogenous and stationary, as required by Tsay (1998). The threshold values are then derived endogenously via grid searches.

We run the Tsay test to assess the presence of threshold effects in the VAR model. Rejecting the null hypothesis (i.e., $H_0: \gamma_t$ is linear) implies concluding in favour of a TVAR specification. Four values of the threshold delay parameter $d$ are considered, so that $d = (0, 1, 2, 3)$. A delay integer equal to zero implies a contemporaneous (within a month) relationship between the VIX ($b_t$) and the other variables in the system, while a delay integer equal to three can be interpreted as a delay of a quarter. Since financial markets tend to react almost immediately to a rise in perceived risk, testing for longer delays does not seem appropriate. The stability of the results is assessed performing the test for different starting values of the recursive estimation, that is $m_0 = (20, 30, 40)$, where the choice of the values follows Tsay (1998). Conditional on $m_0$, the value of $d$ associated with the maximum of the test statistic $C(d)$ indicates the appropriate threshold delay integer.

The linearity assumption is rejected at the one percent significance level for any given value of $d$ and $m_0$ and results are stable across alternative choices of the latter. Concerning the delay integer $d$, the test selects $d = 0$ as the appropriate choice, regardless of the starting value $m_0$.

### 3.2 Modeling a TVAR: threshold values

Due to the limited number of observations, we consider only a two-regime TVAR model ($s = 2$). That is, we allow for only two volatility states of the economy.

Under $s = 2$, the threshold variable splits the sample endogenously into two parts: a “low volatility regime”, which collects all the observations associated with values of VIX lower than the estimated threshold value $\hat{\gamma}_1$ and a “high volatility regime”, which collects the remaining observations.

We use the grid search method with 300 grid points to select the threshold value. Under $s = 2$, we limit the search between the $25^{th}$ percentile and the $75^{th}$ percentile of the empirical distribution of our threshold variable $b_t$. This choice ensures that each regime contains a minimum number of observations without imposing strong restrictions on the location of the estimated threshold value.

The estimated threshold value $\hat{\gamma}_1 = 0.18$ meaning that each time the VIX is below (above) the threshold of 18% the corresponding observation is assigned to the low volatility regime (high volatility regime): 0.18 corresponds to the $58^{th}$ percentile of the empirical distribution of the VIX in our sample.

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17Stationarity is assessed via the Augmented Dickey-Fueller (ADF) Test.
18Refer to Footnote 10: $m_0 = 3\sqrt{96} \sim 30$, where $n=96$ denotes the total number of available observations.
19Under $s > 2$, potential issues in estimation may arise due to the presence of limited data in each regime.
This result is consistent with economic intuition: the upper regime includes a lower number of observations than the downside counterpart, as it collects periods of tensions in the markets. This sub-sample is large enough to include not only rare events, like the recent financial crisis, but also periods where tensions have been considerably higher than in normal circumstances.

4 Results

The final aim of our exercise is to obtain impulse responses conditional on different regimes. To that end, we use both classical and bayesian techniques. First, we use the Tsay test to detect non-linearities and recover the value of the threshold to split the sample in two regimes. Then, in order to mitigate the problems stemming from the small samples available, we use bayesian methods. In particular, we use a non-informative prior (Jeffreys prior) distribution on parameter space and an inverse Wishart distribution as the conjugate prior for the covariance matrix. Antithetic acceleration is then used to improve convergence of the Monte Carlo draws. In all estimated VARs identification is reached through a simple Cholesky decomposition. In figure 1 we report the results of our estimates in both regimes to an increase in asset purchases equivalent to 1 per cent of GDP. The differences in the two regimes are striking. When markets are under pressure, the asset purchase shock has a significant impact on economic activity, inflation and all other variables in the system. All signs are as expected: the 10 year yield decreases reaching a trough after five quarters; asset prices have a stronger and more front loaded response, increasing by more than 3% after 6 months; the VIX decreases by 3 percentage points in four months; GDP increases by 0.3% after 16 months, while the CPI increases by 0.4% after 7 months.\textsuperscript{20}

The Board of Governors of the Federal Reserve System has estimated a cumulative effect of the Federal Reserves Securities Holdings (roughly $4.5 trillion) on Longer-term Interest Rates of about 100bp.\textsuperscript{21} Back of the envelope calculations using our estimates suggest a not dissimilar result: the response (at peak) to a total 1.6 trillion expansion is slightly more than 30 basis points. Moreover, considering the uncertainty surrounding our estimates the two results would be not statistically different.

None of the above effects are detectable in the low volatility environment: the effects on all variables are barely different from zero, except for GDP and CPI, which move in a counterintuitive fashion. This confirms the importance of accounting for non-linearities.\textsuperscript{22} While in the next session we will show that the counterintuitive effects will

\textsuperscript{20}The lagged response of GDP is consistent with what found in Peersman (2011) for the euro area.
\textsuperscript{22}As an alternative informal test of the presence of non-linearities due to different volatility regimes, we update the estimates of the linear WW model to include most recent data, and find that impulse response functions consistent with a marginally significant fall of real GDP and a mitigated response (although still positive and significant) of the CPI. Considering that - according to our own estimates - the added three years of data belong almost entirely to the low volatility regime, the change in WW’s results, which may be considered an across regime estimates, have a clear cut interpretation: when more
vanish when some alternative proxies of market distress are used, it is nonetheless worth mentioning two arguments that might explain the negative impact on GDP. First, it might be the case that the actual balance sheet expansion is consistently greater than the expected expansion exactly during high volatility episode. This would mean that balance sheet expansion would translate into an expansionary shock only in the high volatility regime. Second, a balance sheet expansion engineered during a low volatility (no market distress) period, if interpreted by the market as the central bank having private information about some negative upcoming economic development, might negatively impact growth expectation.

5 Robustness

To gauge the robustness of previous results we concentrate on possible alternative variables to be used as threshold. As threshold variables are meant to proxy the degree of market distress we look at three other alternatives already explored in the literature. First, the Chicago Fed’s National Financial Condition Index (NCFI) which provides a comprehensive update on U.S. financial conditions in money markets, debt and equity markets, and the traditional and shadow banking systems. Positive values of the NCFI indicate financial conditions that are tighter than average, while negative values indicate financial conditions that are looser than average. The three subindexes of the NCFI (risk, credit and leverage) allow for a more detailed examination of the movements in the NCFI. Like the NCFI, each is constructed to have an average value of zero and a standard deviation of one over a sample period extending back to 1971. As second threshold we use the risk subindex (NCFIRISK) which captures volatility and funding risk in the financial sector; again a positive value for an individual subindex indicates that the corresponding aspect of financial conditions is tighter than on average, while negative values indicate the opposite. As a third option we use the excess bond premium (EBP) of Gilchrist and Zakrajek (2012) where an increase in the excess bond premium reflect a reduction in the risk-bearing capacity of the financial sector. In figure 2 we report results for the NCFI. The similarity between the IRF obtained with VIX and those obtained with a different threshold are striking. Again, while in the regime where financial markets are under stress, the GDP moves significantly in the expected direction after an LSAP shock, it does not move in the low NCFI regime where market are not under pressure. Also the responses of equity prices and the long term rates move in the expected direction only in the high NCFI regime. In figure 3 we report the estimates obtained with the subcomponent of the NCFI meant to capture volatility and funding observations in the low volatility regime are added to the full sample estimation, impulses tend to be tilted to the one obtained in this latter regime. In the 36 months from May 2014 to May 2017, the VIX was above the threshold only 4 times.

23The three alternatives were suggested by an anonymous referee to whom we are indebted for this.
26Admittedly, using NCFI we recover a significant effect on the CPI which is unclear through which channel is taking place.
risk in the financial sector. Using this subcomponent we obtain impulse responses that are in line with our baseline results. In figure 4 we report results obtained using the EBP. In this case, the results are even more consistent with our economic argument: LSAP is effective when the market dysfunction channel is on, when this is not the case economic variables barely move conditional on an LSAP shock.

Conclusions

Our results are in line with and actually contribute to explain a simple evidence: the shrinking of the Fed balance sheet did not produce a significant increase in long term interest rates and in stock market volatility, nor a negative impact on asset prices because market were not distressed during that period; the VIX was low (below 13%) for most of the time since the beginning of 2017.\footnote{In early 2018, though, the VIX did increase above the threshold; to the extent that part the unwinding in the balance sheet takes place in this new environment some drag on the economic activity may be expected.}

Admittedly, our result could be influenced by the fact that we focus on a period where the ZLB was binding most of the time, and that a binding ZLB could in fact represent another condition (together with a high volatility regime) for asset purchase policy to be effective. While we cannot discard such possibility, it is worth remembering that during the past six US recessions the average reduction of the federal funds rate target was about 4 percentage points on average (figure 4), which means that the ZLB is likely to be binding also in future recessions, as argued in Kiley and Roberts (2017).

In this paper, to the best of our knowledge, we provide the first empirical evidence on the presence of non-linearities in the transmission mechanism of the unconventional monetary policy deployed through the balance sheet. While at this stage we acknowledge that important caveats remain, we believe this is a promising avenue of research which may prove useful in reconciling different results recovered in the empirical literature on the effects of unconventional monetary policy.
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Figure 1: Response functions in the high volatility regime (VIX ≥ 18%) and in the low volatility regime (VIX < 18%) to a 1 percentage point increase (in GDP terms) in the asset purchases. On the vertical axes the percentage deviation of the levels of the variables.
Figure 2: Response functions in the high NCFI regime (NCFI ≥ -0.54) and in the low NCFI regime (NCFI < -0.54) to a 1 percentage point increase (in GDP terms) in the asset purchases. On the vertical axes the percentage deviation of the levels of the variables.
Figure 3: Response functions in the high NCFIRISK regime (NCFIRISK $\geq$ -0.41) and in the low NCFIRISK regime (NCFIRISK $<-0.41$) to a 1 percentage point increase (in GDP terms) in the asset purchases. On the vertical axes the percentage deviation of the levels of the variables.
Figure 4: Response functions in the high EBP regime (EBP ≥ -0.2) and in the low EBP regime (EBP < -0.2) to a 1 percentage point increase (in GDP terms) in the asset purchases. On the vertical axes the percentage deviation of the levels of the variables.
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