Macroeconomic Effects of Monetary Policy : A Yield-curve approach

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Macroeconomic Effects of Monetary Policy: A Yield-curve approach

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A thesis presented in partial fulfilment of the requirements of the degree of Master of Philosophy

School of Economics

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Abstract

I estimate the macroeconomic effects of monetary policy shocks between 1996-2013 using Inoue and Rossi 2018's functional shock approach based on identifying shocks as shifts in the entire term structure of the yield curve around monetary policy announcements. The empirical framework is unique in how it provides a tool to study monetary policy across conventional and unconventional periods within a unified model. The principal contribution of this work is documenting the relationship between the nature of shifts induced in the yield curve by a monetary policy announcement and its macroeconomic impact. I find that shocks in the conventional period that have a larger impact on the long-term yields elicit similar macroeconomic responses as those in the unconventional period, with the responses being in line with standard theory. I also find that shifts in the long-term rates are policy-relevant and cannot be ignored even in the conventional period. Additionally, I correct the shock measure for information frictions and find the results to be qualitatively similar, but with a roughly two-fold magnification of the responses.

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1 Introduction

In recent years, Central banks all over the world have been faced with the unique constraint of operating under the zero-lower bound (ZLB), where the short-term interest rates are stuck at near-zero levels. Traditional measures of monetary policy that identified monetary policy shocks as unanticipated changes in the short-term rates are unreliable in this "unconventional" period of monetary policy, posing a major challenge for economic researchers and policymakers.

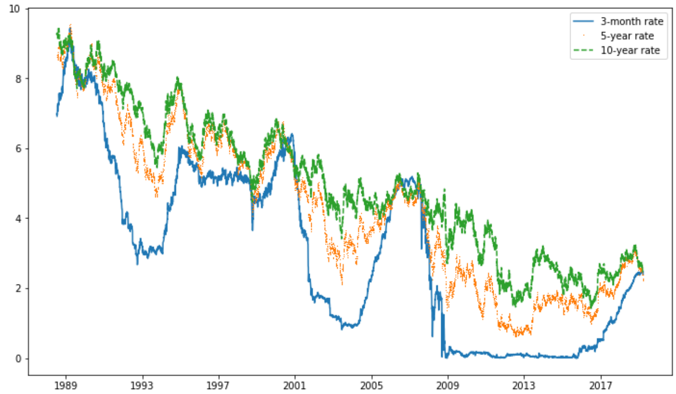


Figure 1: Evolution of yields (1990-)

The Global Financial Crisis of 2008 caused all yields to fall to record low levels

The Global Financial Crisis and the subsequent Central Bank interventions triggered a steep fall in the yields at all maturities. Particularly, November 2008 marks the lowering of the 3-month treasury rate to the effective zero lower bound and the beginning of the unconventional period of monetary policy in the US. In terms of studying the macroeconomic effects of monetary policy, this development sets the landscape for methods that can capture aspects of monetary policy shocks beyond just shifts in the short-term rates.

Measuring monetary policy shocks as shifts in the entire yield curve around a monetary policy announcement allows us to capture aspects of monetary policy in a much broader context, one that is reliable even in the zero-interest rate regime. In this thesis, I use this new approach pioneered by Inoue and Rossi 2018 to study the effects of monetary policy shocks in both the conventional and the unconventional period of monetary policy in the US within a unified framework. Importantly, while their work focuses on estimation of the macroeconomic response of monetary policy shocks, I aim to understand what factors influence these responses and whether they depend on the nature of Central Bank policy at large.

How does the impact on the yield curve determine the macroeconomic effect of a monetary policy shock? Is the nature of the macroeconomic impact different between the shocks in the conventional and the unconventional period? And lastly, how much of a role does the transmission of information by the Central bank play? I use Inoue and Rossi 2018's framework to address these foundational problems in monetary macroeconomics.

I find that the macroeconomic effects of a monetary policy shock depend not just on how the short-term rates change but also on shifts in the longer term interest rates. This is found to be true even in the conventional period of monetary policy in the US, in contrast with standard results in the VAR literature. I also find that considering only the shocks in the conventional period that primarily affect the longer term yields, the responses are qualitatively similar to the shocks in the unconventional period. Unconventional monetary policy shocks are also found to be just as effective at moving the macroeconomy as shocks in the conventional period. Additionally, I find that accounting for information transfer by the Central bank leads to qualitatively similar results and a roughly two-fold amplification of the responses.

The rest of this thesis is structured as follows: Section 2 goes over literature related to this study. Section 3 details how the monetary policy shocks are measured and identified in this framework, following Inoue and Rossi 2018. In Section 4, I discuss some stylistic features of the yield curve during the conventional and the unconventional period. Section 5 describes the econometric model used for estimation of the impulse responses of macroeconomic variables to monetary policy shocks and presents the baseline results. Lastly, in Section 6 I present empirical results after correcting for information effects using the method described in Miranda-Agrippino and Ricco 2019.

2 A Review of the Literature

Typically, literature concerning monetary policy during normal times (pre-GFC) derives the monetary policy shocks as unanticipated changes in the instantaneous rates, or the effective Federal funds rate. This forms the traditional "money shock" literature on monetary policy analysis, surveyed in Christiano, Eichenbaum, and Evans 1999. The study of monetary policy during the unconventional period presents a unique challenge in that the shock instrument commonly used in monetary policy literature, the Fed funds rate is practically zero in this period. This results in Central banks being forced to rely on unconventional monetary policy instruments such as forward guidance, Quantitative Easing (QE) and Large Scale Asset Purchase (LSAP) programs. The present work occupies a space within a fairly novel pocket of literature that seeks to unify the study of monetary policy across the two periods, agnostic to the particular instrument used.

The GFC of 2008 landed major economies around the world into a regime only familiar to Japan, which has been stuck in a deflationary, zero-interest regime since 1999. Oda and Ueda 2007 examine the effects of Japan's zero-interest commitment on medium- and long-term interest rates. They find that the commitment has been effective in lowering the expectations component of interest rates, especially with short- to medium-term maturities.

This is supported by Eggertson and Woodford 2003 who argue that unconventional monetary policy can favorably effect lowering long-term yields only if such policy serves as a credible commitment to keep the interest rates below the natural rate even after the economy recovers. Clouse et al. 2003 argue that such a commitment can be achieved if the Central bank purchases a large quantity of long-maturity assets, so that if the rates are raised the bank loses money. These results form the foundation of the rationale behind the QE and LSAP programs.

Gagnon, Raskin, Remache, and Sack 2011 find that the Fed's LSAP program led to long-lasting reductions in long-term interest rates across a range of securities, caused primarily due to reduction in risk premia. However, Krishnamurthy and Vissing-Jorgensen 2011 show that QE purchases involving highly "safe" assets only work to drive down the yields of assets of similar risk profiles such as Treasuries and not necessarily ones that are policy relevant such as corporate securities. Bernanke, Reinhart, and Sack 2004 conduct a review of alternative monetary policy to examine its efficacy within an event-study framework. They find favourable evidence for the role of Central bank communication in shaping the markets' expectations about the future and point towards price-level targeting as a possible focus for monetary policy in the future. On the other hand, Hamilton and Wu 2012 find that while the Fed has the potential to flatten the yield curve by selling short-term securities and buying long-term securities, the scale of the operations required to have any significant impact would be massive. The entire ability of the Central bank to influence long-term yields comes from influencing expectations about economic fundamentals after the ZLB is lifted. Wright (2012) argues based on heteroskedasticity-identified daily VARs that while the stimulative effects of unconventional monetary policy cannot be ignored, they were quite modest and short-lived with a half-life of about two months.

Another important tool for monetary policy analysis that has become prominent in the post-ZLB era is shadow rate. The shadow rate is conceptualised as a measure derived from the dynamics of the yield curve that remains consistent as a proxy for monetary policy both within and outside of the ZLB. The idea of shadow rates is based on the first seminal work of Black 1995, who derived a measure based on the yield curve that could turn negative, thus being unconstrained by the ZLB. Krippner 2012 adds an explicit function of maturity to the shadow rate forward curve, thus giving models with closed-form solutions. Krippner 2013 then applies the shadow rates to the study of the liquidity trap in Japan. J. Wu and Xia 2014 use a different formulation of the shadow rate to the study of monetary policy in the US and find their effects to be similar to the effects of the Fed funds rate. While the shadow rates are consistent across the ZLB constraint, they are still a scalar measure of monetary policy and are unable to capture shocks to different aspects of monetary policy such as coupled effects of shifts in funds rate and forward guidance, while the measure proposed by Inoue and Rossi 2018 used in this thesis can.

A key building block of modern monetary macroeconomics is the high-frequency identification literature. High-frequency identification has gained support over the recent years because of the ease with which it enables the researcher to surmount the orthogonalization problem in shock identification in VARs. It is not always easy to pinpoint whether one set of variables reacts to the other or vice-versa, especially for monthly data.

Pioneered by Cook and Hahn 1989, high-frequency methods have been made a popular tool in macroeconomic research by Kuttner 2001, who uses changes in Fed funds futures around monetary policy announcements to disentangle the effects of anticipated and unanticipated component of monetary policy on a set of interest rates across maturities. Cochrane and Piazessi 2002 perform variations on this analysis, incorporating high-frequency measures of monetary policy shocks into a VAR framework.

Borrowing from the tradition of the high-frequency approaches outlined above, Gertler and Karadi 2015 compose a measure of monetary policy shocks as a linear combination of shocks to current and future expected short rates, which include a set of fed funds and Eurodollar futures. By allowing for the shock measure to incorporate changes in expectations about the future,

Gurkaynak, Sack, and Swanson 2005 derive measures of monetary policy shocks by measuring changes in a set of interest rates (Fed funds futures, Treasury yields and Eurodollar futures) within a 30-minute window of monetary policy announcements and considering their principal components. They find two factors to be sufficient in describing the shocks in their sample that includes data up to 2004. E. Swanson 2019 performs a similar analysis on the post-2009 sample period and finds three factors to be important in describing the shifts in the set of interest rates. Thus, there is evidence in the literature pointing towards more dimensions of monetary policy being relevant than just the instantaneous rate.

The analysis presented within this thesis falls within the class of high-frequency identification methods and is based on the work of Inoue and Rossi 2018. In their paper, the authors propose the idea of using the entire shift in the yield curve in a 1 day window around a monetary policy announcement as the monetary policy shock, incorporating a multi-dimensional shock measure. The key difference in their work and my work in this thesis is that I aim to go beyond estimating the impulse responses and try to understand how the nature of these responses are related to the nature of the shifts in the yield curve.

Several studies have tried to shed light on how the yield curve responds to monetary policy. Ellingsen and Soderstrom 2001 classify monetary policy actions as endogenous and exogenous based on their readings of news reports from Wall Street Journal. They estimate changes in interest rates across maturities as a response to the change in the 3-month rate around the monetary policy announcement. They find that for the "endogenous" monetary policy events, long-term interest rates move with the short-term rates, while the opposite is true for the "exogenous" events. Romer and Romer 2000 argue that policy surprises lead to an increase in the long-term rates, due to long-run inflation expectations being revised upwards. This is related to information channel of monetary policy that I discuss later in this section.

Closely related to my work is the literature studying the dynamic linkages between the yield curve and the macroeconomy. A commonly used model within this strand of literature is the Nelson-Siegel model of the yield curve. Diebold, Rudebusch, and Aruoba 2006 use a modified version of the Nelson-Siegel model that allows for state-space dynamics. They incorporate macroeconomic factors along with yield curve factors as part of a dynamic VAR model. They find the macroeconomic factors to have a strong influence on future yield curve factors, while also finding yield curve factors to have a weak reverse influence on future macroeconomic variables. Moench 2012 performs a similar study but with factors derived from a wider set of macroeconomic variables and with larger lag lengths, while also allowing yield curve factors to contemporaneously affect macroeconomic variables. He also finds the curvature factor to precede a strongly significant and persistent hump-shaped movement of the yield curve slope and a persistent decline of the level factor, and thus mark economic slowdowns.

The bulk of the research on the dynamics of the yield curve are related to the expectations hypothesis. The expectations hypothesis posits that long-term yields are just the future expectations of the average short term yields. Gürkaynak and Wright 2012 review models of the yield curve from the point of view of the expectations hypothesis. They find that the expectations hypothesis performs well as long as long-run inflation expectations are well-anchored.

Lastly, pertaining to my analysis in Section 6 about the information effects of monetary policy, I discuss some papers addressing the role of information frictions in monetary policy transmission. Romer and Romer 2000 find evidence for the information channel of monetary policy by comparing Fed's inflation forecasts with that of commercial forecasters. They claim that the Fed has superior information about economic fundamentals, that is conveyed through monetary policy action. Private agents and market participants then use this revealed information to update their beliefs. Nakamura and Steinsson 2018 find similar evidence for the "information channel" of monetary policy, finding empirical evidence for market expectations of output and inflation to rise following a monetary tightening. They contend that the market infers a monetary tightening as a signal for Fed's optimism about current and future economic prospects. This results is also echoed by the findings of Campbell, Evans, Fisher, and Justiniano 2012

Gertler and Karadi 2015 also find evidence for Fed having an information advantage over the market. They compose a measure of Fed's "private information" by taking the difference of the Fed's forecast for a variable and the Blue Chip Economic Indicators forecast as the proxy for market's information. Then they regress their shock measure on this private information and obtain the "clean", information-robust shocks as the residuals of the regression. Romer and Romer 2004 create a new "narrative" measure of monetary policy shocks by regressing the intended funds rate against its own macroeconomic forecasts. The intended funds rate is inferred from FOMC meeting notes and memos, while the internal forecasts are obtained from the Greenbook. The residuals from this regression are then, the "true" shocks free of endogenous adjustments.

Miranda-Agrippino and Ricco 2019 provide evidence for the presence of information frictions relevant to monetary policy. They find that shocks identified through high-frequency methods are predictable and autorocorrelated, owing to the sluggish adjustment of expectations. They further show that these shocks are correlated with the Central bank's private forecasts. To account for these, they create a measure of monetary policy shocks that are unforecastable and are free of the Central bank's own assessment of economic fundamentals. I follow the methodology outlined in their work to obtain shocks that are robust to information frictions and estimate the macroeconomic responses to these "information robust" shocks in Section 6.

3 Measuring the monetary policy shocks

Since I measure monetary policy shocks as shifts in term structures, it would be ideal to have the shifts represented by just a few parameters for the estimation to be tractable. The Nelson-Siegel model of the term structure achieves this, providing a parsimonious representation of the yield curve while being able to fit the changes remarkably well. The model is given by the equation:

$$y_t(\tau) = \beta_{1t} + \beta_{2t}(\frac{1-e^{-\lambda\tau}}{\lambda\tau}) + \beta_{3t}(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}) \quad (1)$$

where $y_t(\tau)$ denotes the yield at maturity τ and time t; λ is a calibrated parameter.

Diebold and Li 2006 have calibrated λ by maximising loading on the medium term to the value 0.0609, which is what I use throughout this work. β_1, β_2 and β_3 may be interpreted as the level, slope and curvature factors respectively.

Another advantage of using the Nelson-Siegel model is that the factors also lend themselves to simple economic interpretation. A change in β_1 would reflect as a parallel shift in all the maturities. A change in β_2 reflects as a shift in the short-term rate relative to the long-term rate. β_3 governs the concavity of the curve, with most of the effect on the intermediate maturities. The instantaneous yield, or the short-term rate is $y_t(0) = \beta_{1t} + \beta_{2t}$, and the asymptotic long-term yield is $y_t(\infty) = \beta_{1t}$.

Monetary policy shocks are identified as changes in the entire term structure of interest rates around monetary policy announcement. Following Inoue and Rossi 2018's specification, the shocks are measured as the changes in each of the β factors. The shock resulting from a monetary policy announcement at time t would hence be represented as $(\Delta\beta_{1t}, \Delta\beta_{2t}, \Delta\beta_{3t})$. Thus the shock in the specification used in this thesis is a vector of the individual changes in the Nelson-Siegel factors within a 1-day window of monetary policy announcements.

This form of estimation entails making the following assumptions:

1. relevance: movements in the yield curve on monetary policy dates are only due to monetary policy shock
2. exogeneity: movements in the yield curve outside a 1-day window of monetary policy announcements are not due to the monetary policy shock

Gurkaynak, Sack, and Swanson 2005 show that for a sample beginning after 1994, daily data can be used to reliably measure monetary policy shocks and hence, the first assumption holds. Additionally, since the announcement dates are exogenous, it is reasonable to assume that the shifts in the yield curve within a one-day window would also be exogenous. Under these assumptions, the monetary policy shocks are identified as the change in each of the three Nelson-Siegel factors in a one-day window around a monetary policy announcement.

4 Monetary Policy and the Yield Curve

The period between 1995 and 2016 has been of particular significance from the perspective of macroeconomics and monetary policy. Between the conventional and unconventional period of monetary policy in the US, marked by the Global Financial Crisis of 2008 all yields fell to record low levels. I find that apart from a fall in the level of term-structure, there was a de-sync between the short and the long-term rates as the correlation between them also decreased dramatically. I also find that the impact of monetary policy shocks on the yield curve are markedly different in the two periods. Some aspects of these changes are explored in this section.

	Conventional period			**Unconventional period**		
	3m	**5y**	**10y**	**3m**	**5y**	**10y**
3m	1			1		
5y	0.879	1		0.612	1	
10y	0.757	0.97	1	0.04	0.736	1

Table 1: Correlation between yields at different maturities in the two periods

The behaviour of the yield curve presents some peculiar features with the beginning of the unconventional monetary policy in the US. Table 1 reports the correlation coefficients[1] between three representative yields (with maturities 3 month, 5 year and 10 year)[2]. As can be seen, all three yields are highly correlated in the conventional period. In the unconventional period, the co-movement between both the 10-year yield and the 3-month yield and the 10-year yield and the 5-year yield fall sharply.

		$\lvert\Delta Y_{3m}\rvert$	$\lvert\Delta Y_{5y}\rvert$	$\lvert\Delta Y_{8y}\rvert$	$\lvert\Delta Y_{10y}\rvert$
Conventional	Mean	0.084	0.081	0.080	0.080
	Std dev	0.123	0.065	0.065	0.066
Unconventional	Mean	0.018	0.092	0.112	0.121
	Std dev	0.017	0.077	0.097	0.106

Table 2: Comparison of shifts in the yield curve between the two periods

Another important aspect in which the behaviour of the yield curve changes between the two periods is illustrated by Table 2, which describes the mean shift

[1] the correlation coefficients are calculated as $\rho = \frac{cov(x,y)}{\sqrt{var(x)var(y)}}$

[2] All correlations were statistically significant at 95%

in four representative fitted yields around monetary policy announcements. In the conventional period, all yields move largely by the same step size in reaction to a monetary policy announcement, but in the unconventional period, the step size increases with maturity. Moreover, in the conventional period, the standard deviation of the steps is highest for the 3-month yield and the same lower value for the others, indicating that the short-term yield was especially variable during that period. In case of the unconventional period, the variability in step size displays a similar trend as that of the mean step, in that it's increasing with maturity. These facts are consistent with a picture of the yield curve that mainly shifts in level in the conventional period, with the short-term rate being particularly responsive to monetary policy. In the unconventional period, the short-term rate becomes particularly unresponsive and shifts in the yield curve may be viewed as rotations about the origin with most of the variation at the longer maturities.

5 Estimating the macroeconomic effects

In this thesis, I estimate the impulse responses of macroeconomic variables to the monetary policy shocks by the method of local projections (Jorda 2005). Local projections belong to a class of direct-forecast methods that do not rely on specifying the underlying DGP for estimation of impulse responses, thus making them more robust to model mis-specification in limited samples. I go over some theoretical aspects of local projections along with related literature on their estimation in Appendix A. Within this section, I estimate impulse responses to the shocks identified in Section 3 and determine the macroeconomic responses to each of the monetary policy announcements within the sample.

Following Inoue and Rossi 2018, the local projection regression is characterised by the equation:

$$X_{t+h} = \mu_h + \Gamma_2^h(L)\Delta\widetilde{\beta_{2,t}} + \Gamma_3^h(L)\Delta\widetilde{\beta_{3,t}} + A(L)X_{t-1} + u_{t+h}^h \tag{2}$$

where X_t is a time series containing the macroeconomic variables of interest, in this case Industrial Production growth and CPI inflation at monthly frequency i.e, $X_t = \begin{bmatrix} X_t^{ip} \\ X_t^{cpi} \end{bmatrix}$. The local projection is estimated for the sample period 1996:01 to 2013:12. I estimate the local projections up to 20 months ahead and with 3 lags of the shock variable and the macro variables.

$$\Gamma_i^h(L) = \sum_{s=0}^{s=p} \Gamma_{i,s}^h L^s \quad A(L) = \sum_{s=0}^{s=p} A_s L^s$$

$\Delta\widetilde{\beta_t} = \Delta\beta_t.d_t$, d_t is an indicator variable for if a FOMC meeting took place that month and $\Delta\beta_t$ is the monetary policy shock recorded as the shift in a 1-day window around a monetary policy announcement. Hence, I assign the shock a value of $\Delta\beta_t$ for the month in which the announcement took place and zero for months with no announcements. In a few cases, there are multiple announcements in a month. For those months, I take the sum as the shock.

I exclude $\widetilde{\Delta}\beta_{1,t}$ from the regression since I find $\widetilde{\Delta}\beta_{1,t}$ and $\widetilde{\Delta}\beta_{2,t}$ to be collinear within the sample period that I use for estimation.*[3] So $\Delta\widetilde{\beta_{2,t}}$ and $\widetilde{\Delta}\beta_{3,t}$ are sufficient to capture the monetary policy shock and estimate the impulse responses within the sample.

I estimate the local projection regression in the full sample (1996:01-2013:12) instead of splitting the sample at the beginning of the unconventional period as in Inoue and Rossi 2018. I find that this is appropriate since this gives us a larger sample to estimate the transmission coefficients since otherwise the sample sizes would be too small for this fairly high-dimensional econometric setup and (ii) since shifts in the yield curve remain a consistent measure of shocks across both periods.

From the local projection, the impulse response of Industrial Production growth X^{ip} to a unit shock in $\Delta\beta_i$ is given by $\Gamma_{i,0}^{h,ip}$ and that of CPI is given by $\Gamma_{i,0}^{h,cpi}$. Figure 2 shows the estimated impulse responses of Industrial Production growth and CPI inflation at each horizon to unit shocks in β_2 and β_3.

Since each realisation of a monetary policy shock is a change in the vector-valued $\widetilde{\Delta\beta_t} = [\widetilde{\Delta\beta_{2,t}}; \widetilde{\Delta\beta_{3,t}}]$, what is of interest to us is the total impact of an announcement on a macroeconomic variable at some horizon 'h', given by:

$$\frac{dX_{t+h}}{d\epsilon_t} = \frac{\partial X_{t+h}}{\partial \widetilde{\Delta\beta_{2,t}}}\Delta\widetilde{\beta_{2,t}} + \frac{\partial X_{t+h}}{\partial \widetilde{\Delta\beta_{3,t}}}\Delta\widetilde{\beta_{3,t}} \tag{3}$$

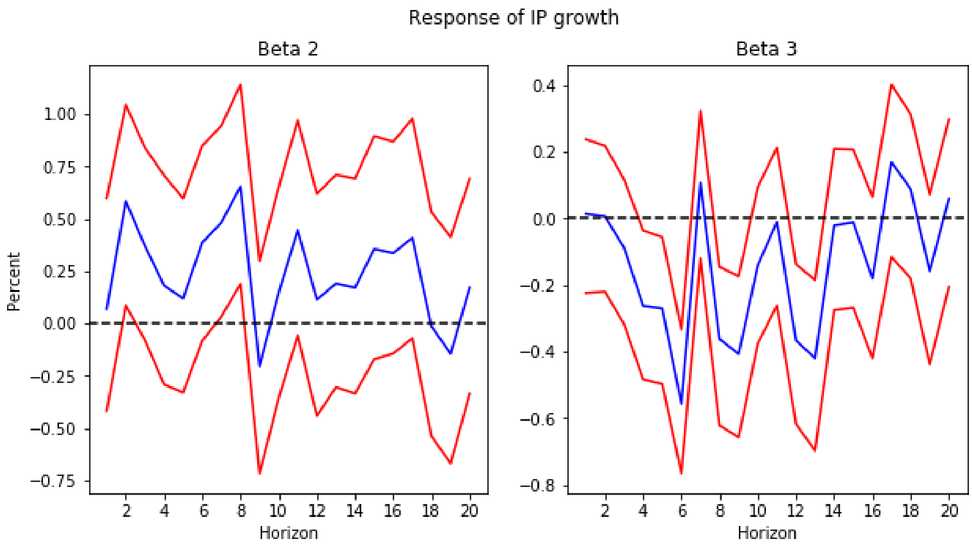
Expressed in terms of the local projection coefficients,

$$\frac{dX_{t+h}}{d\epsilon_t} = \Gamma_{2,0}^{h}\Delta\widetilde{\beta_{2,t}} + \Gamma_{3,0}^{h}\Delta\widetilde{\beta_{3,t}} \tag{4}$$

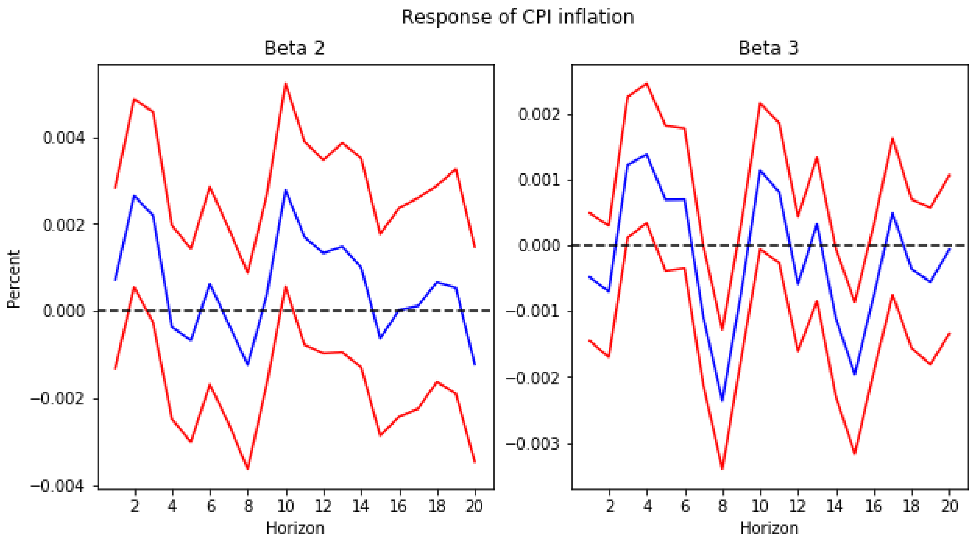
Hence the impact on the macroeconomic variables of each shock would be distinct both in scale and in shape based on the nature of the shock itself.

The computation of standard errors for the coefficients of the local projection must be robust to HAC error terms, since the errors have a moving average structure (Jorda 2005). Also, since the regressors are themselves estimated from the yield curve and not directly observed, standard Newey-West HAC correction

[3] t-stat=-13.72 for correlation



(i) Impulse response of IP growth to shifts in β_2 and β_3



(ii) Impulse response of CPI inflation to shifts in β_2 and β_3

Figure 2: Factor-specific impulse responses

Note: The impulse responses are estimated from eqn. (2) to unit shocks in each of the factors. The figures report 95^{th} percentile confidence intervals

would not take the additional uncertainty into account (Pagan 1984). For this reason, standard errors are estimated using the stationary bootstrap procedure. The details of the bootstrap procedure are discussed in Appendix A.

Using local projections for estimation results in much wider confidence bands than VARs, as explored in Miranda-Agrippino and Ricco 2019. They suggest using Bayesian Local Projections that achieve a trade-off between the flexibility of a local projection framework combined with the precision of a VAR. As optimal inference is outside the scope of this thesis, I report results from the local projections discussed above, though inference can be improved.

5.1 Data

I use a sample period between 1996:01 and 2013:12 since this period covers both conventional and unconventional monetary policy. The yield curve data is available at a daily frequency following 1990. I use data from FRB H-15 and Gürkaynak, B. Sack, and J. Wright 2007's database for the yields. I use maturities up to 10 years, owing to inconsistencies in the data for higher maturities and also liquidity constraints posed by the bonds. I obtain the Greenbook forecasts from the Fed website. The Greenbook forecasts needed for estimating information effects are only available up to 2013:12, restricting the sample.

I get the monthly data for Industrial Production(INDPRO) and CPI Inflation (CPIAUCSL) from Federal Reserve Bank of St. Louis' FRED.

5.2 Empirical Results

From the impulse response coefficients estimated using local projections above, the response of output and CPI inflation to each monetary policy announcement can be thought of as a distinct linear combination of the responses to the individual β factors multiplied by the respective shift caused due to the announcement. This results in announcement-specific responses for each monetary policy announcement event. I report my results in the terms of cumulative response of the Industrial Production growth and CPI Inflation variables at each horizon, i.e., output and price-level responses. Responses to some noteworthy announcements are given in Appendix B.

The sample period includes 145 monetary policy announcements in total, each having a distinct macroeconomic response associated with it. In order to understand the link between the shifts induced in the yield curve by an announcement and its macroeconomic effect, we must consider ways to group monetary policy announcements by the nature of the shifts they induce upon the yield curve and then summarise the responses.

To aid comparison between shocks of the same nature in the two periods, shocks are classified on the basis of how they affect the yield curve at different maturities. I classify the shocks as in Inoue and Rossi 2019.

The classification scheme takes into account effects beyond just the shifts in the short term rates in the conventional period. For shocks in the conventional period, the ones that induce a fall in the 3-month rate but an even larger fall in the 5-year rate are labelled "fully expansionary" shocks. Similarly, shocks that cause the 3-month rate to rise, but also cause the 5-year rate to rise by an even larger magnitude are labelled ”fully contractionary” shocks. For shocks during the unconventional period, since the short-term rates are stuck near zero, the shift in the 5-year rate is used as the metric for classification. I compare the effects of the fully expansionary and fully contractionary shocks in the conventional period against those of the expansionary and contractionary shocks during the unconventional monetary policy period in the US. The classification is described below:

Conventional period

- Fully contractionary: $\Delta y^*_{1/4,t} > 0$ and $\Delta y^*_{5,t} - \Delta y^*_{1/4,t} > 0$
- Fully expansionary: $\Delta y^*_{1/4,t} < 0$ and $\Delta y^*_{5,t} - \Delta y^*_{1/4,t} < 0$
- More Contractionary at Short: $\Delta y^*_{1/4,t} > 0$ and $\Delta y^*_{5,t} - \Delta y^*_{1/4,t} < 0$
- Less Expansionary at Long: $\Delta y^*_{1/4,t} < 0$ and $\Delta y^*_{5,t} - \Delta y^*_{1/4,t} > 0$

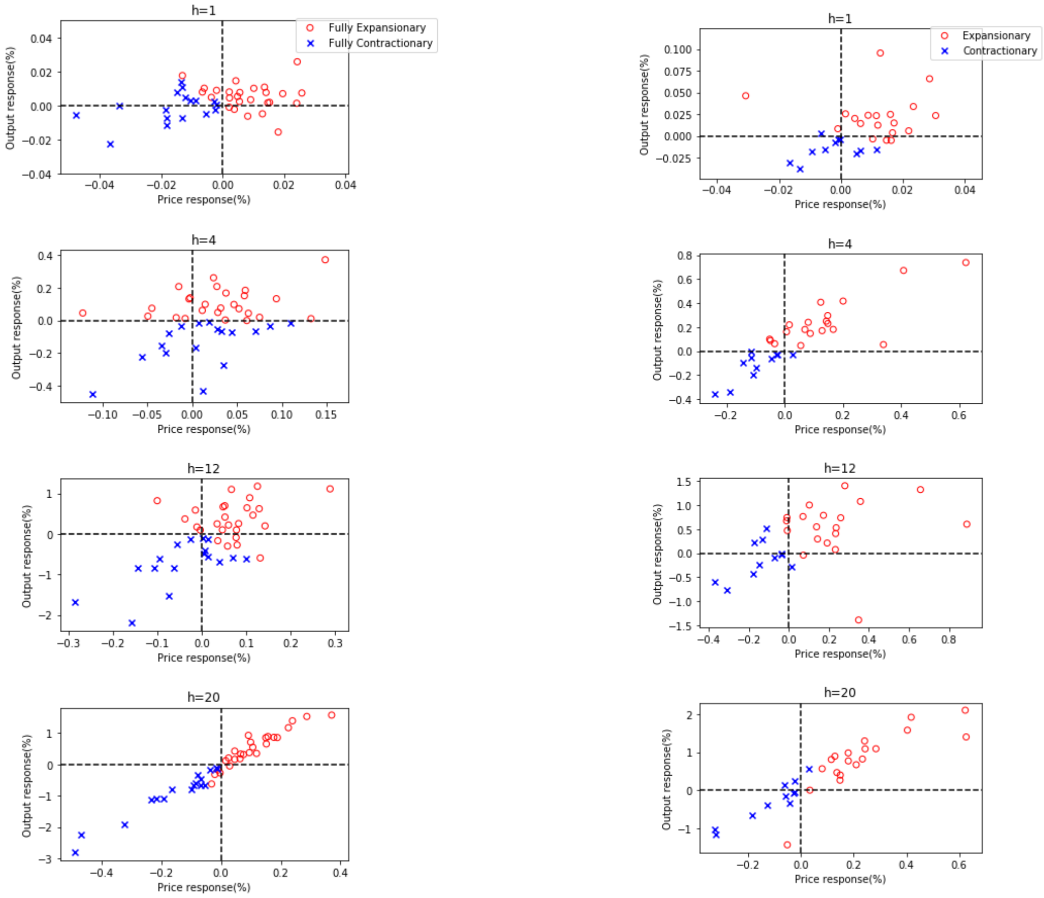
Unconventional period

- Contractionary: $\Delta y^*_{5,t} > 0$
- Expansionary: $\Delta y^*_{5,t} < 0$

where Δy^*_τ represents the shift in the fitted value of the yield at maturity τ in years.

This is done so that unconventional monetary policy shocks, which typically have larger impact on the long end of the yield curve can be compared against shocks of similar shape characteristics in the conventional period.

To visualise the relationship between the nature of the shocks and the macroeconomic response, I plot the point estimates of the output and the price level responses at four representative horizons (h=1,4,12 and 20 months after impact) for each shock. Each monetary policy announcement in the sample is represented as a point in the plot. The summarised responses are reported in Figure 3



Conventional Period *Unconventional Period*

Figure 3: Responses of macroeconomic variables to monetary policy shocks

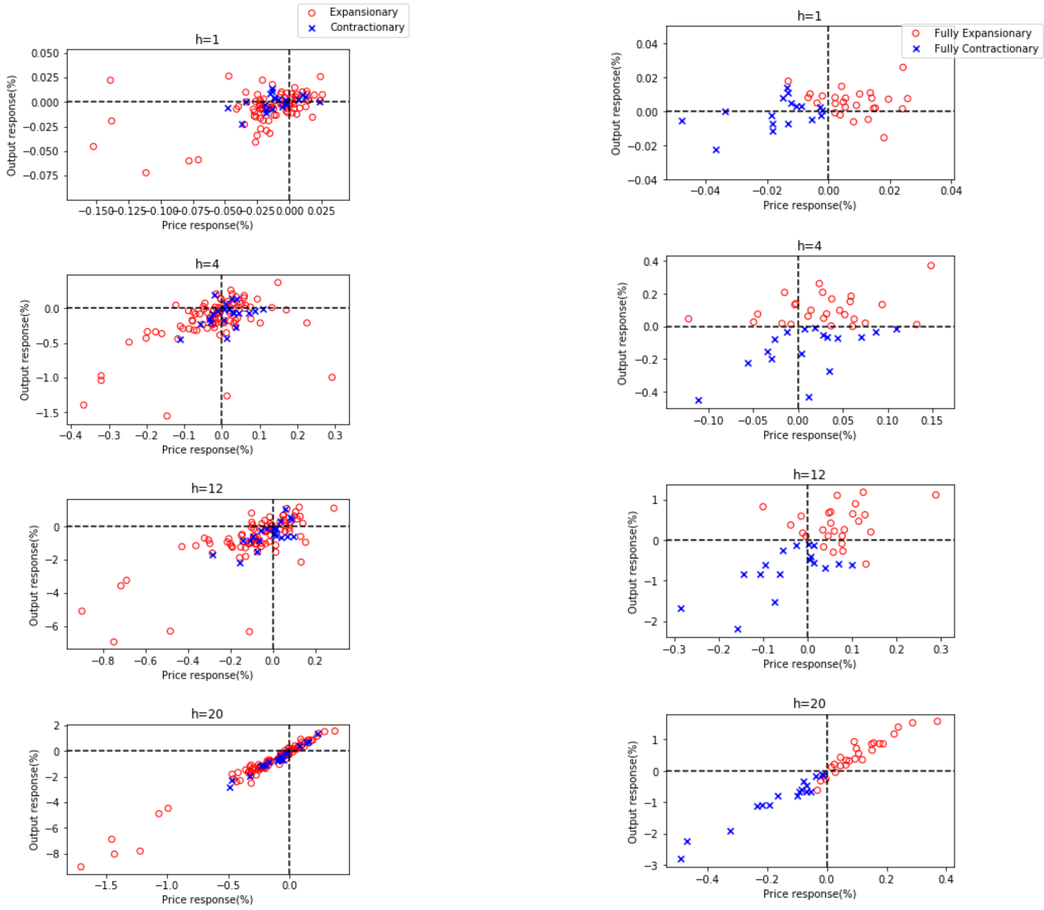
Notes: Each point represents the point estimate of the output (Industrial Production) and price (CPI) level responses at different horizons. The shocks are classified as discussed in Section 5.1

The responses in both periods mirror what one would expect from theory with both, output and price level rising following an expansionary monetary policy announcement event and falling after a contractionary announcement (see Figure 3). For most of the responses, the impact on price level is quite muted and is not statistically significant even at longer horizons for most shocks. The shocks during the unconventional period also seem to have a larger output response on impact as compared to the ones during the conventional period. These results also indicate that even in the unconventional period, Central bank policy remains relevant in moving the macroeconomy and does not lose effectiveness. This finding points towards Swanson 2019's argument that the Fed's LSAP and forward guidance in the unconventional period are about as effective as policy tools as the funds rate during normal times and that the Fed retains its ability to transmit monetary policy through the medium and longer-term rates.

Next, I ask whether shifts in the long-term yields matter during the conventional period. In the baseline, we have a classification of shocks that is based on not just the effects of the yield curve on the short term maturities, but also on how the shocks shift the longer maturities of the yield curve. This is in contrast with traditional literature on monetary policy which classify shocks based on the impact on short-term maturities alone. Hence, it is would be interesting to see if shifts in the longer term maturities are important at all with regards to the macroeconomic response to monetary policy shocks inducing them. Here I report the results from an alternate classification based on the effects of the monetary policy shock on the 3-month yield alone as:

- Contractionary: $\Delta y^*_{1/4,t} > 0$
- Expansionary: $\Delta y^*_{1/4,t} < 0$

From Figure 4 it is seen that classifying the shocks based on the shifts at the short end of the yield curve alone, the stylistic features of the responses in line with theory are lost and there is no clear distinction between the responses to the contractionary and expansionary shocks. This points towards the importance of the changes in the long-term yields in moving macroeconomic aggregates even in the conventional period of monetary policy in the US. This is an aspect of monetary policy that traditional literature tends to miss or understate. Recent literature, including Gurkaynak, Sack, and Swanson 2005 lend support to the view that long-term rates and forward guidance have been important in driving the macroeconomic variables much before the GFC of 2008.



(i) Classified based on shifts in short-term rate (alternative)

(ii) Classified based on entire effect on yield curve (baseline)

Figure 4: Comparison between responses to shocks during conventional period under two classifications

Notes: Each point represents the point estimate of the output (Industrial Production) and price (CPI) level responses at different horizons. The shocks are classified as discussed in Section 5.1

6 Information Effects

Do central banks implicitly transfer private information to the market through policy actions? This forms the basis of the information channel of monetary policy which states that the market infers information about real economic fundamentals from Central Bank policy announcements. If these effects are significant, it could lead to monetary policy shocks being incorrectly identified and giving rise to erroneous responses. Hence, it is important to investigate the presence of information effects. I use the methodology devised by Miranda-Agrippino and Ricco 2019 to correct for information released by the Fed using Fed's Greenbook forecasts [4]. Within the sample, I find that correcting for information effects leads to qualitatively similar output and price level responses as without them, but with markedly larger magnitudes.

Miranda-Agrippino and Ricco 2019 find evidence that commonly used shock measures in high-frequency literature[5] are: (i) serially correlated, and (ii) correlated with the revisions in Fed's private forecasts on key macroeconomic variables between meetings and (iii) have a high degree of predictability conditional on macroeconomic factors. Thus, the raw measures of shocks may not be appropriate for macroeconomic analysis and can produce spurious results. They attribute the "puzzles" observed in Gertler and Karadi 2015's results to bias resulting from not accounting for information transfer from the Fed. Motivated by this idea, they develop a new measure that is orthogonal to its own lagged values and also to Fed's forecasts, thus resulting in a series of "true shocks".

Following their methodology, I form a time series of information-corrected shocks in the next subsection. The shock series are then used in the local projection as in Section 5 to derive macroeconomic responses.

6.1 Correcting the shock measure for information effects

The construction of the shock measure must take into account transfer of information from the Fed forecasts during monetary policy announcements and also purge the shocks of any predictability thus accounting for the slow absorption of information. This is achieved by first regressing the estimated shift in each of the yield curve factors around a monetary policy announcement m on the Fed's macroeconomic forecasts upto some quarters ahead from the latest meeting and also on the shifts in these forecasts relative to the previous meeting and considering the residual as the shock. The regression is:

$$\Delta\beta_m = \alpha_0 + \sum_{j=-1}^{1} \theta_j F_m^{cb} x_{q+j} + \sum_{j=-1}^{1} \upsilon_j [F_m^{cb} x_{q+j} - F_{m-1}^{cb} x_{q+j}] + I\bar{R}I_m \qquad (5)$$

Here, q represents the running quarter at the time of meeting m and hence $F_m^{cb} x_{q+j}$ represents the Central bank's forecast at meeting m for the variable x, $q+j$ quarters ahead. Thus, the first term of the regression accounts for information about forecasts released at meeting m and the second term represents the shift

[4] Greenbook forecasts are prepared before FOMC meetings and hence represent forecasts under constant policy

[5] These are the monthly market surprises extracted form the fourth federal funds futures, and constructed as the sum of daily series in Gurkaynak, Sack, and Swanson 2005; the average monthly market surprise in Gertler and Karadi 2015, and the Romer and Romer 2004's narrative shock series

in the forecast relative to meeting $m-1$.

This gives a shock measure at announcement frequency. Then I form a shock measure at monthly frequency by aggregating the shocks across all announcements in that month [6]. The non-zero values of the series thus obtained, $\overline{IRI_t}$ are then regressed on their lags according to:

$$\overline{IRI_t} = \phi_0 + \sum_{j=1}^{6} \phi_j \overline{IRI_{t-j}} + IRI_t \tag{6}$$

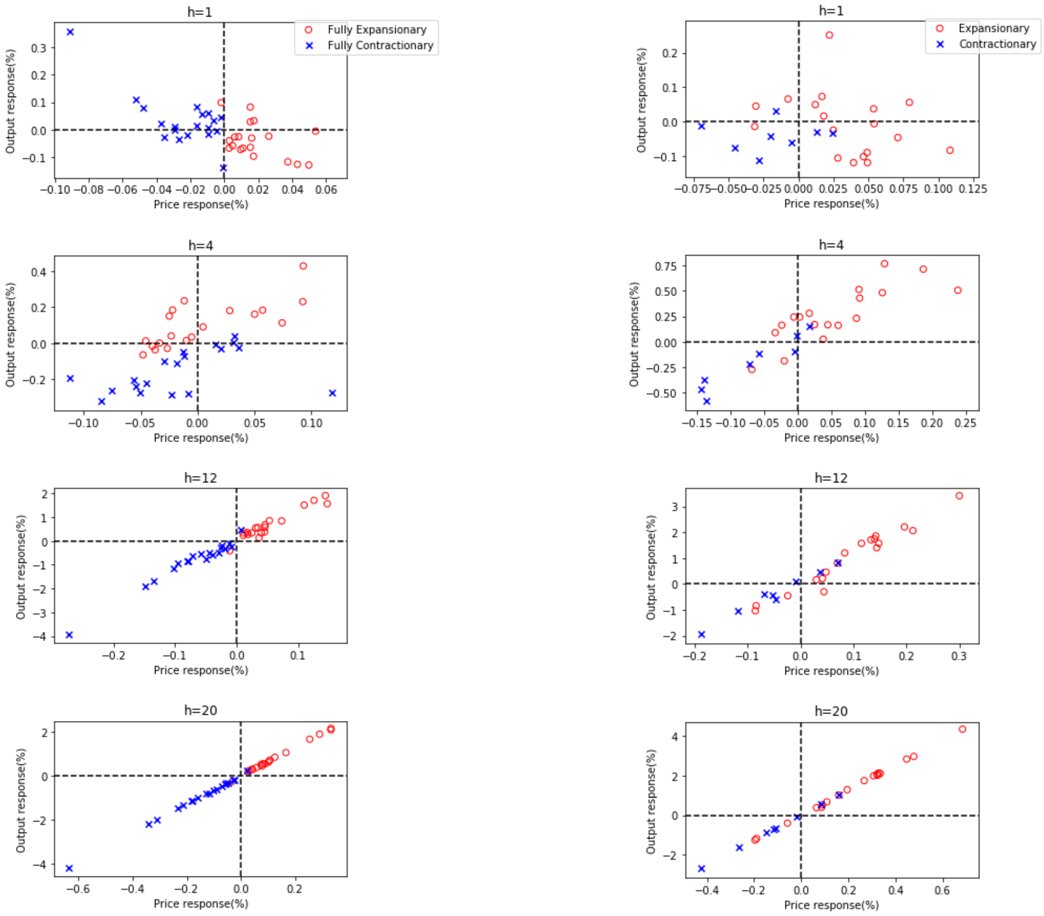
This is done so that the predictable component of the shock is eliminated. This accounts for the slow absorption of information by the private agents after a monetary policy announcement (Coibion and Gorodinichanko 2015). The informationally robust instrument IRI_t is thus obtained as the residual of the regression. For months without any monetary policy announcements, IRI_t is zero.

6.2 Empirical Results

Similar to results in Section 5, the responses to the information-robust shocks in the conventional as well as the unconventional period are reported in Figure 5. It can be seen that the responses to shocks in both periods are qualitatively similar to the ones obtained for the raw shock instrument before correcting for information transfer. The expansionary shocks still cause output and prices to increase, with the opposite being true for contractionary shocks for both the periods. The long-run responses, in both periods are about twice as large in magnitude as the responses obtained for the raw instrument. Thus, taking information effects into account increases the magnitude of the responses to the shocks, while retaining similar qualitative features from before.

In contrast with what Miranda-Agrippino and Ricco 2019 find, I do not find evidence for any puzzles in the baseline results. I find that the response of real activity is in accordance with theory. This result is in line with Hoesch, B. Rossi, and Sekhposyan 2020's claim. They contend that the information advantage of the Central bank has diminished over the recent years and disappeared sometime in the early-mid 2000s. They find that private forecasters stopped updating their expectations for real variables and interest rates following monetary policy announcements after 2004. According to them, this loss of information advantage has also led to the information channel of monetary policy not being relevant as far as the macroeconomic effects are concerned.

[6] Typically there is not more than one announcement within a month, but in particular cases there were two (due to unscheduled FOMC meetings as well as notable speeches made during the unconventional period) and in those cases, the sum was taken to be the shock measure for the month.



Conventional Period *Unconventional Period*

Figure 5: Responses to Information robust shocks

Notes: Each point represents the point estimate of the output (Industrial Production) and price (CPI) level responses at different horizons. The shocks are classified as discussed in Section 5.1

I note that the sample period used by Miranda-Agrippino and Ricco 2019 in their study covers the period 1979-2014. When this sample is split and only the period 1995-2014 is analysed, I find that the puzzles reported in their study are not observed. Hoesch, B. Rossi, and Sekhposyan 2020 reports a similar result, splitting the sample at 2004 and concludes that the information effects are not policy-relevant for samples beginning post-2004. The magnification in the size of the responses is in agreement with Gertler and Karadi 2015 who find that after cleaning their shock measure for Fed's private information, the fall in output and inflation in reaction to a monetary contraction is larger than in the baseline.

7 Conclusions

There is a vast literature exploring the links between the yield curve and the macroeconomy (Diebold, Rudebusch, and Aruoba 2006, Moench 2012). The monetary policy literature has also emphasised on Treasury yields as an important instrument for monetary policy (Gurkaynak, Sack, and Swanson 2005, E. Swanson 2019). The principal contribution of my work is to unite these two strands of literature and explain the link between shifts in the yield curve impacted by monetary policy announcements and the resulting macroeconomic responses. Further, I address whether monetary policy during the conventional and the unconventional period are fundamentally different in how they operate or are they similar. The results presented in this thesis support the latter view.

Using the functional shock approach pioneered by Inoue and Rossi 2018, measuring monetary policy shocks as the entire change in the yield curve around a monetary policy announcement, I find that the particular nature of the shift in term structure describes a crucial aspect of monetary policy shocks that is important in determining the responses of macroeconomic variables. Expansionary shocks during the conventional period identified as having a larger expansionary effect on the long-term yields have similar macroeconomic effects as the ones during the unconventional period. This also supports Swanson(2019)'s view that the zero-lower bound does not diminish the Fed's ability to impact the macroeconomy though, by means of medium and longer term yields as opposed to the short-term yields.

I also find that in the conventional period, characterising shocks only based on changes on the short-end of the yield curve leads to effects inconsistent with theory. This is supported by evidence from Gurkaynak, Sack, and Swanson 2005 that forward guidance was operational even in the early 2000s and shifts in the long-term rates were important even in the conventional period.

Further, I find that accounting for information effects of monetary policy leads to qualitatively similar conclusions, except for a roughly two-fold increase in the magnitude of the responses. This finding lays further emphasis on Hoesch, B. Rossi, and Sekhposyan 2020's result that the Fed's information effect has weakened in the recent years and may not be policy-relevant.

The recent literature on the effects of monetary policy documents the need for researchers to look beyond short-term rates and lays emphasis on tools like forward guidance and LSAPs to understand the implications of Central bank policy. Inoue and Rossi 2018's framework provides us with a tool that is agnostic to the particular policy instrument used and hence econometrically simple and yet leads us to key results that are in agreement with notable insights from recent literature on monetary policy, showing a lot of promise for future research in the area.

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8 Appendix A: Estimation of Impulse Responses using Local Projections

The method of local projections for estimation of impulse responses was proposed by Jorda 2005. Local projections are one among a family of direct forecast methods commonly used in empirical literature. In contrast with with iterated forecasts, that rely on arriving at an accurate estimate of the DGP (typically a Markovian DGP like VAR) and then inverting it to get the impulse responses, responses are directly obtained by regressing the series some horizons ahead onto the lagged values.

Consider a [T x n] vector time series y_t. We project the leading series at horizon h (y_{t+h}) onto the linear span of $(y_{t-1}, y_{t-2}, ...y_{t-p})$ where 'p' denotes the number of lags. The local projection regression, then is:

$$y_{t+h} = \alpha_h + B_1^h y_{t-1} + B_2^h y_{t-2} + \cdots + B_p^h y_{t-p} + u_{t+h}^h$$

The impulse response at horizon h is simply $IRF(h) = B_1^h$

In contrast, a VAR specifies a linear relationship between y_t and $X_t = (y_{t-1}, y_{t-2}, ...y_{t-p})'$ so that:

$$y_t = \mu + \Gamma X_t + e_t$$

where $\Gamma = [A_1 A_2 ... A_p]$ Assuming invertibiilty, the fundamental innovations can be recovered as a linear combination of the VAR residuals as:

$$\eta e_t = \epsilon_t$$

where e_t is an i.i.d vector of disturbances.

The impulse response of variable 'i' to variable 'j' at horizon h is then given by $\theta_{i,j}^h$, where:

$$\theta^h = \eta (A_1)^h$$

The advantage of local projections is that we do not have to make structural assumptions about the underlying DGP. The impulse responses are estimated directly without the need to invert the VAR, so mis-specification errors don't propagate at larger horizons as they would if a VAR were mis-specified. Jorda 2005 argues that local projection estimates are less efficient when the VAR is correctly specified and is the true model, even though the loss of efficiency is not particularly significant.

Plagborg-Møller and Wolf 2019 argue that VARs and local projections estimate the same impulse responses in population, estimated with infinite lag length. When estimated with finite lag length 'p', they find that the responses agree up to horizon 'p' and then diverge. The small sample performance of local projections are thus not strictly better or worse than VARs, but simply depend on the DGP considered.

Choi and Chudik 2019 find that parsimonious models perform better in small sample in simulation studies. Brugnolini 2018 finds that local projections perform better in cases where true DGP is ambiguous, but worse when the true DGP is a VAR. Jorda 2005 also finds local projections to outperform VARs under mis-specification in simulations.

8.1 Bootstrapping standard errors for responses

Within this study, I use the estimated change in the Nelson-Siegel factors around monetary policy announcements as the regressors in the local projection. Since these regressors are estimated and not directly observed, any traditional HAC correction, such as the Newey-West correction would not take this additional uncertainty into account and should preferably be avoided. (Pagan 1984)

Hence, within my study, I use bootstrap procedures to compute standard errors for the local projection in Section 5. The method I use particularly to account for the autocorrelation in the error terms in the local projection is the Stationary Bootstrap by Politis and Romano 1994.

Consider bootstrapping a time series regression model $y = \Gamma X + \epsilon$ where y is a [T x 1], X is a [T x k] matrix of 'k' regressors, and ϵ is a [T x 1] vector of errors.

Let the estimated regression be $y = \hat{\Gamma} X + e$, with e being the [T x 1] vector regression residuals.

In a simple residual bootstrap (used in the context of local projections in E. Swanson 2019), bootstrap samples are generated as $y_{MC} = \hat{\Gamma} X + e_{MC}$ where each element of e_{MC}, e^i_{MC} is randomly sampled from elements of the [T x 1] vector e with replacement.

This method of bootstrap is appropriate when the error structure of the regression model is known to be homoskedastic. With heteroskedastic, auto-correlated standard errors however, the residual bootstrap scheme is not tractable.

The stationary bootstrap belongs to a class of moving block bootstrap procedures where the residuals are divided into blocks of length 'l' and the sampling procedure includes sampling observations from entire blocks. Let B_i describe the block consisting of l observations beginning with e_i i.e

$$B_i = [e_i, e_{i+1}, ..., e_{i+l-1}]$$

The moving block bootstrap consists of sampling blocks B_{i_1},B_{i_2}... where i_1, i_2 are independent, identically distributed sampled from [1,2,...,,T] under a discrete uniform distribution.

A pseudo vector e^* is generated with the first i_1 terms being the terms of B_{i_1} in order, the next i_2 terms from B_{l_2} and so on. Pseudo-residual time series of any length can then be generated as $y^* = \hat{\Gamma} X + e^*$.

This process may be repeated 'NMC' times (where NMC represents the number of Monte Carlo replications) to get the set of pseudo-vectors $[y^*_1, y^*_2, ..., y^*_{NMC}]$. The pseudo vectors are then regressed on the regressors X to get the bootstrap sample of estimates $[\Gamma_1, \Gamma_2, ...\Gamma_{NMC}]$ from which any statistic of interest may be calculated.

The drawback of the Moving Block Bootstrap is that the pseudo-time series obtained may not be stationary even though the original time series is stationary. This leads us to stationary bootstrap that generates stationary pseudo time-series conditional on the initial vector e.

Within the stationary bootstrap, instead of sampling blocks of fixed length 'l', blocks of random length are sampled from the Binomial distribution, with a parameter p that is chosen considering the expected lag order. The starting position of a block, i is uniformly distributed over [1,2,...T]. Blocks, are then constructed as

$$B_{i,l} = [e_i, e_i, ...e_{i+l-1}]$$

$$i \sim unif(1, 2, ..., T)$$

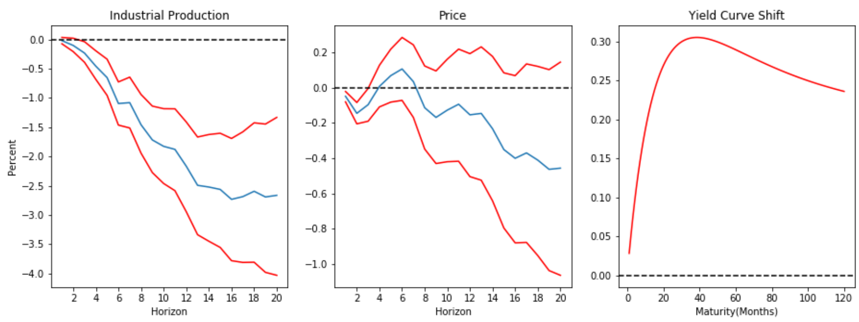
$$l \sim Bin(p)$$

Blocks B_{i_1,l_1},B_{i_2,l_2},... are thus obtained and a pseudo vector e^* is generated from these blocks and a pseudo time series y^* is obtained using the point estimate $\hat{\Gamma}$. Independent repetitions of this procedure results in a bootstrap sample for Γ as before from which statistics may be calculated.

9 Appendix B: Responses to Selected Shocks

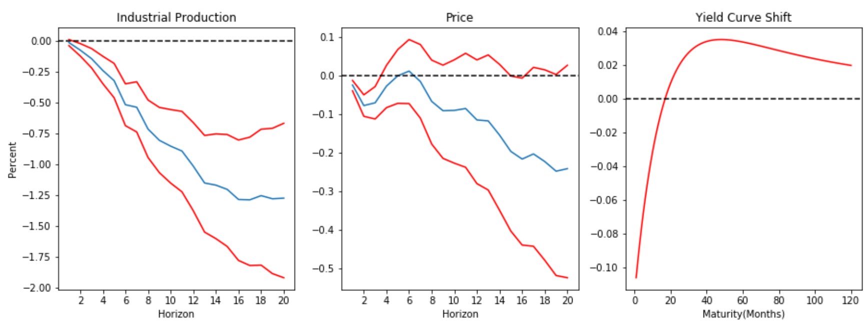
9.1 Responses to some notable monetary policy events during the conventional period

June 25, 2003:[7] FOMC announced that it was lowering its target for the federal funds rate from 1.25% to 1%. The market expected rates to be lowered by 50 bp. The shock is hence registered as contractionary, despite the rates actually being lowered, with the 3-month rate rising by 9 bp. Industrial production falls by about 2 percent, with the effect peaking at around 18 to 20 months since impact. Price remains relatively stable.



Response to "fully contractionary" shock of Jun 25, 2003

December 21, 1999: FOMC announced that it was keeping the target rate unchanged at 5.5%, but hinted at rate hikes in the coming months. Owing to inflationary pressure, market analysts were expecting a rate hike. Fed's decision to keep rates unchanged led the 3-month rate to fall by 4 bp, while the announcement made the market shift expectations for future path of rates upwards, resulting in a 6 bp increase in the 30-year rate.

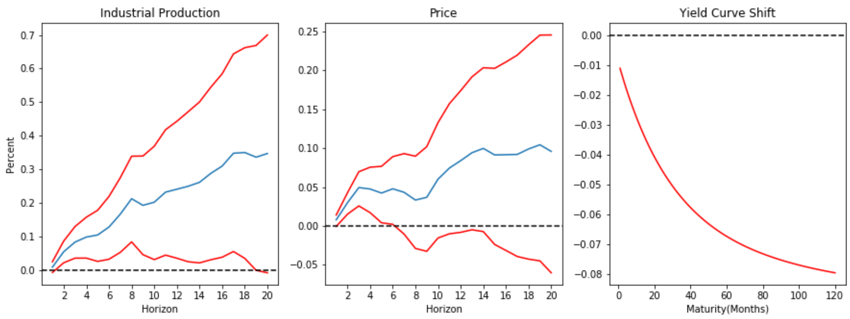


Response to "expansionary on the short end" shock of Dec 11, 1999

March 16, 2004: FOMC decided to keep the target rate unchanged at 1%. It

[7] The figures here report the total response of macroeconomic variables to the announcement shock along with 75%-ile confidence intervals

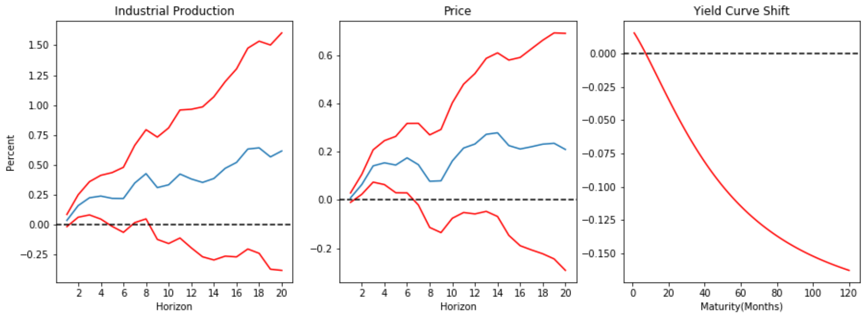
further stated that owing to low levels of inflation, it could be patient in removing policy accommodation. In the shock that I measure, the yield curve shift is muted at the short-term but there is a significant fall in the long-term yields possibly in response to Fed's indication that rates would remain low longer than what the market expected.



Response to "fully expansionary" shock of Mar 16, 2004

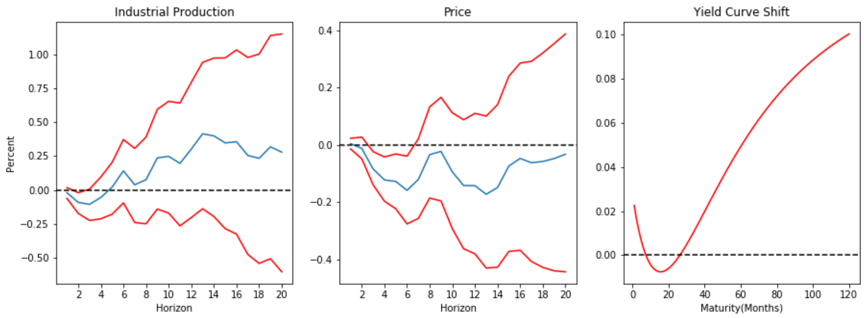
9.2 Responses to some notable monetary policy events during the unconventional period

November 3, 2010: FOMC announces it will purchase an additional $600B of longer-term Treasuries, initiating QE-2.The yield curve is impacted heavily at the long end by this announcement, falling by about 8 bp.



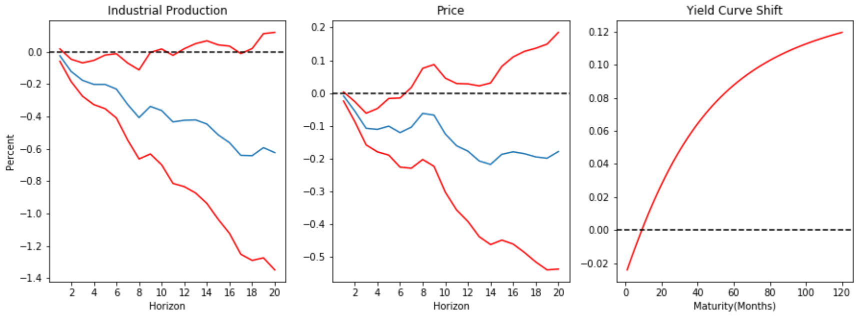
Response to "expansionary" shock of Nov 3, 2010

September 13, 2012: Start of LSAP-3. FOMC announces it expects to keep the federal funds rate between 0 and 25 bp “at least through mid-2015”, and that it will purchase $40B of mortgage-backed securities per month for the indefinite future.



Response to "contractionary" shock of Sept 13, 2012

December 18, 2013: FOMC announces it will start to taper its purchases of longer-term Treasuries and mortgage-backed securities to paces of $40B and $35B per month, respectively. This is known as the 'taper tantrum' that led to speculation that QE is ending sooner than expected. This led to a spike in the yield curve, and had contractionary effects.

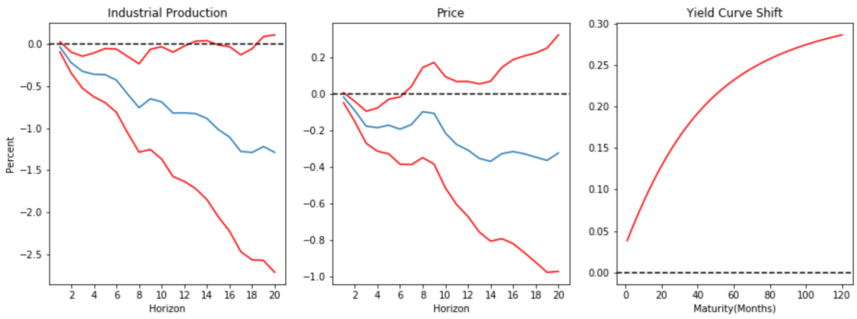


Response to "contractionary" shock of Dec. 18, 2013

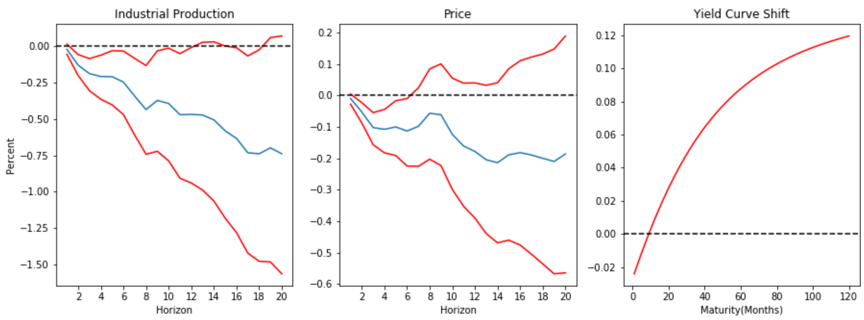
10 Appendix C: Contractionary shocks during the Unconventional period in the US

I find that some shocks in the unconventional period elicit contractions in output. Since this might point to an aspect of unconventional monetary policy in the US that is often overlooked, I look at the FOMC announcements on these dates and find context for what happened. I find that for many of these dates, the news revealed in the announcement does in fact indicate contractionary sentiments in line with the responses I observe. I list some of these dates along with the responses, calculated based on shifts in the yield curve. [8].

Narrative context for some selected dates

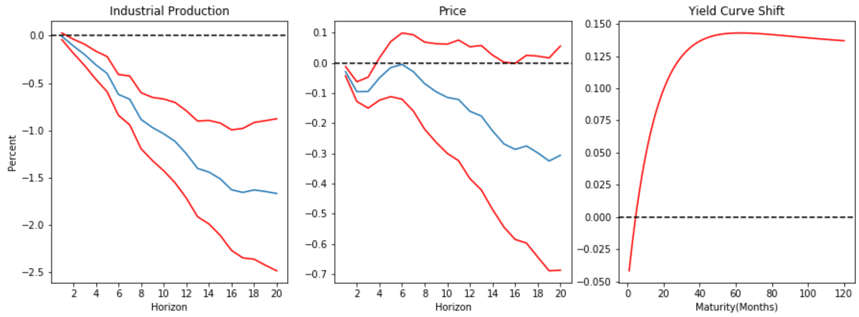


28 January, 2009: FOMC meeting perceived as disappointing by the markets

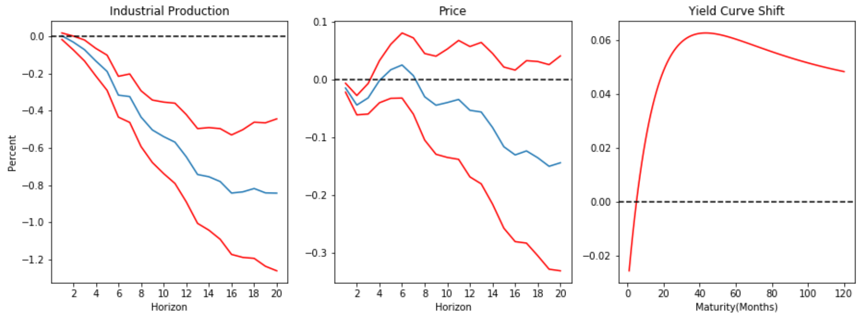


18 December, 2013: Tapering of QE

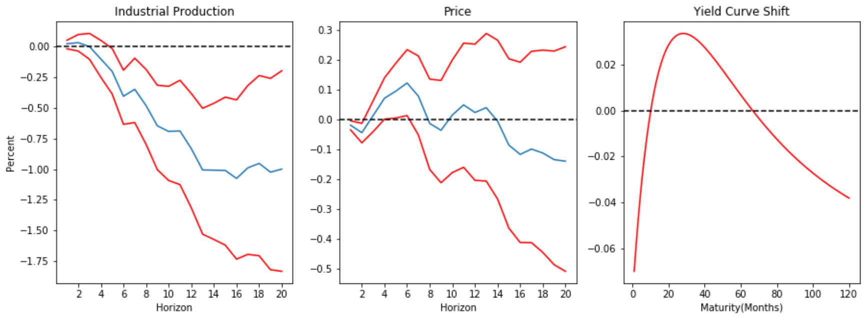
[8]The figures here report the total response of macroeconomic variables to the announcement shock along with 75^{th} percentile confidence intervals



3 March, 2014: Possibility of raising the Fed funds rate 6 months after the end of QE



17 September, 2014: Reduced QE purchase by another $10 billion



16 December, 2015: Raised fed funds rate a quarter point to 0.5 percent