An Alternative Approach to Estimate the Impact of the Fed's Balance Sheet Policies[†]

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Abstract

Treasury auctions of ten-year notes provide a natural way to isolate exogenous changes in longer-term interest rates that are orthogonal to conventional monetary policy shocks. On auction days, unforeseen variations in the demand for ten-year Treasuries generate a preferred habitat-like effect on the yield curve, which operates mainly via changes in the term premium. Using high-frequency changes in yields around auction closure, I identify shocks to longer-term interest rates that mimic shocks to the Fed's balance sheet policies and estimate that Large Scale Asset Purchases (LSAPs) or balance sheet expansions sharply reduce credit spreads and generate a persistent increase in economic activity. When the federal funds rate is unconstrained, balance sheet normalization dampens economic activity and increases credit spreads modestly, but increases inflation. The findings demonstrate the link between balance sheet policies, economic activity, and interest rates, which previous work examining the impact of LSAPs has been unable to show empirically.

JEL Classification Codes: E32, E43, E44, E52

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"*...the Federal Reserve's purchases of longer-term securities, by lowering term premiums, put downward pressure directly on longer-term interest rates. By easing conditions in credit and financial markets, these actions encourage spending by households and businesses through essentially the same channels as conventional monetary policy.*"

Ben Bernanke, March 1, 2011, testimony to the congress as the Chairman of the Board of Governors Federal Reserve System (Bernanke, 2011).

1 Introduction

Following the 2008-2009 financial crisis, balance sheet policies have become an important element in the central banking toolkit. Likewise, between 2017 and 2019 and more recently, policymakers have rolled out balance sheet normalization policies or quantitative tightening (QT). Understanding the mechanism underlying the transmission of balance sheet policies is simultaneously critical and challenging since the Fed undertakes LSAPs after fully utilizing conventional policy tools, accompanied by the fact that the economy is distressed, and the Fed unwinds balance sheets when economic fundamentals are more robust and the ZLB constraint is no longer binding.

This article provides an alternative approach to estimating the economic impact of balance sheet policies. Instead of identifying shocks to balance sheet policies by constructing surprises in the movements of longer term interest rates around FOMC announcements, it exploits the composition of asset purchases undertaken in LSAPs and the fact that these policies aim to impact the economy by directly targeting the longer end of the yield curve, differentiating them from conventional policy and forward guidance as noted in Thus, if it was possible to measure exogenous movements in longer-term interest rates orthogonal to shocks to level and path of the federal funds rate it would constitute a suitable instrument for balance-sheet-policy-related shocks.

The structure of Treasury auctions naturally allows us to extract such unforeseen variations in longer term interest rates. Treasury auctions are not driven by shorter term business cycle fluctuations or the dual mandate guiding monetary policy, and have little influence on the expected path of interest rates which is pinned down by monetary policy. Additionally, the Treasury announces the volume of securities available for purchase several days before the auction, allowing markets sufficient time to react to new information between the announcement and implementation. Thus, changes in yields of long-term Treasuries around a tight-window bracketing the closure of Treasury auctions isolates unforeseen changes in the demand for long-term Treasuries, since no other relevant information is likely released in that window, and mimics shocks to balance-sheet policies.

While the strict interpretation of demand shocks is not necessary as long as the extracted variation reflects unforeseen changes in long term yields, Ray, Droste, and Gorodnichenko (2024) provide extensive evidence regarding how these variations stem from the demand side.[1]

The choice of long-term interest rates in this article is the yield on the ten-year Treasury security. Why focus exclusively on ten-year Treasuries to isolate a measure of shocks to longer-term interest rates? A central component in implementing LSAPs comprises the purchase of longer-term Treasury securities.[2] The ten-year Treasury security is particularly important in this class of longer-term securities since key borrowing costs in the economy, for private nonfinancial borrowers and households, are benchmarked to the ten-year Treasury yield, with the ten-year yield being the relevant risk-free rate. Moreover, the duration of several longer-term mortgage-backed securities is closer to the ten-year maturity.[3] Most importantly, the market for 10-year T-notes and futures is one of the most liquid financial markets globally.

Using auction data between 1998/08 and 2019/12, I calculate surprise movements in ten-year Treasury yields by examining the change in yields of ten-year T-note futures (expiring at the end of the current quarter) around a thirty-minute window bracketing the closure of the auction for ten-year Treasuries. Assuming that ten-year T-Note futures adequately reflect market expectations about ten-year Treasury yields, this approach isolates unforeseen variations in ten-year yields. I show that indeed surprise movements in the yields of ten-year T-Note futures around a thirty-minute window bracketing the closure of U.S. Treasury auctions is a relevant high-frequency instrument for changes in the ten-year Treasury yield explaining close to 20% of the daily variation in ten-year yields. The explanatory power of surprise movements in ten-year futures yields on auction days is largely driven by changes in the term premium. Also, consistent with the preferred habitat theory, on auction days for ten-year Treasuries, unforeseen changes in ten-year yields impact yields of securities with maturities both greater and less than ten years. However, the intensity of impact increases as we move closer to the ten-year maturity mark on either side.

Combined with the relevance of the instrument, the high-frequency identification around a tight thirty-minute window bracketing the closure of auctions for ten-year T-Notes minimizes the possibility of the release of other news or the occurrence of other

[1] If one interprets that Fed and the Treasury as a unified body, then LSAPs can be thought of as a supply shock to Treasury securities available for purchase to the private sector.

[2] The first round of Large-Scale Asset Purchases (QE1) involved the purchase of $300 billion in longer-term Treasury securities, with maturities greater than five years accounting for about 50% of the volume, while the second round (QE2) involved the purchase of $600 billion of longer-term Treasury securities.

[3] For instance, duration on a 30-year mortgage backed security is around 7 years, more comparable to a 10-year Treasury (Krishnamurthy and Vissing-Jorgensen, 2011).

events, thereby guaranteeing that the surprises around auction closure satisfy the exogeniety assumption. This approach thus helps construct a valid high-frequency instrument for shocks to the ten-year yield, which mimics shocks to long-term interest rates stemming from changes in balance sheet policies.

Using this instrument,however, at a monthly frequency by cumulating auction incidences in a month to identify the impact of unforeseen changes in the ten-year yield on macroeconomic activity, as a proxy for balance-sheet-policy shocks, can be challenging since within a month, there may be shocks to the level or the path of the federal funds rate that impact yields on both the short and long end of the Treasury yield curve (including the yield on the ten-year zero-coupon security, which is sensitive to shorter-term monetary policy shocks as well as longer-term balance-sheet-policy-related shocks). Thus, at a monthly frequency, the ten-year yield may not be the appropriate measure of long-term interest rates to study the effectiveness of balance sheet policies since those respond to shorter-term interest rate shocks as well as longer-term LSAP shocks.

To isolate a measure of long-term interest rate impacted by shocks to ten-year T-note futures around U.S. Treasury auctions and unaffected by conventional monetary policy shocks at a monthly frequency, I decompose the ten-year zero-coupon yield into a sequence of continuously compounded one-year forward rates (0-by-1 to 9-by-10). Decomposing the ten-year zero-coupon yield into its constituent forward rates enables the identification of the components that are most sensitive to longer-term shocks and unaffected by shorter-term monetary policy shocks to the level and path of the federal funds rate.

I show that monetary policy shocks (shocks to the federal funds rate and forward guidance) impact the one-year forward rates, used to construct the ten-year zero-coupon yield, only at the short to medium maturity, with the explanatory power of monetary policy shocks in driving high-frequency (daily) changes of one-year forward rates vanishing around the 7-year horizon.[4] The explanatory power of 'conventional' monetary policy shocks is close to zero for the one-year forward rate going from 9 to 10 years. Decomposing the ten-year zero-coupon yield into underlying one-year forward rates thus isolates components of the ten-year zero-coupon yield that are most responsive to surprises to the yield of ten-year T-note futures around U.S. Treasury auctions and unaffected by other monetary-policy-related shocks. In the VAR analysis, therefore, I measure the longer-term interest rate using the one-year forward rate going from nine to ten years.[5]

I calculate the impact of shocks to longer-term interest rates by estimating a monthly

[4]For most of the sample, each month generally has one or no auctions. Hence, the high-frequency surprises and, for those instances, monthly surprises are interchangeable. Similarly, for monetary policy shocks, for the most part, daily (or higher frequency) and monthly surprises are interchangeable.

[5]Measuring longer-term interest rates using the one-year forward rate going from nine to ten years is not a tight requirement. The results remain unchanged if forward rates going from seven to eight or eight to nine years are used instead as the measure of long-term interest rates.

VAR model using Bayesian methods in Miranda-Agrippino and Ricco (2021) with the one-year forward rate going from 9 to 10 years as the measure of longer-term interest rates and data between 1978/01 to 2019/12. The remaining set of endogenous variables comprises the 1-year zero-coupon yield, 10-year zero-coupon yield, Industrial Production, the unemployment rate, the Gilchrist and Zakrajšek credit spread, and the S&P 500, along with one-year-ahead expectations of economic activity and inflation. I identify shocks to the longer-term interest rates using the external instruments approach – the underlying instrument being the surprises to the yields of ten-year Treasury-note futures estimated at a higher frequency and then aggregated monthly.[6] For the baseline analysis, this data extends from 1998/08 to 2019/12.

A one-standard-deviation (about two basis points) decrease in the one-year forward rate, from nine to ten years, which proxies surprise balance sheet expansion, triggers a sharp decline in the credit spread, signaling easing financial conditions. The unemployment rate decreases on impact, and this decline persists. Industrial production increases a few months after the shock, and inflation increases over the medium to long term, although this change is modest and largely insignificant. These findings demonstrate that balance sheet normalization compresses the credit spread with a more than proportionate pass-through rate, stimulating both actual and expected economic activity. When scaled appropriately, a 10-basis-point reduction in long-term interest rates, measured using the forward rate from nine to ten years, generates a peak response in industrial production of 38 basis points and a trough response in the unemployment rate and the credit spread of 22 basis points and 28 basis points, respectively.

In the transmission mechanism, I emphasize the borrowing cost channel as intended by the Fed and show through a counterfactual exercise that if this channel is switched off, almost all of the improvement in economic activity is eliminated. The baseline analysis thus provides strong evidence to support the effectiveness of these policies in stimulating different measures of economic activity.

While the VAR model is linear and the effects are symmetric for a one-standard-deviation increase in the measure of longer term interest rates, when I reestimate the baseline model by only including data when the federal funds rate is unconstrained by the zero lower bound (ZLB), I find that while the unemployment rate and the credit spread still decrease in response to a one-standard-deviation expansion, however, the magnitude is smaller relative to what is estimated for the baseline specification including periods when the federal funds rate is constrained by the zero-lower bound ZLB . In this specification, the response of industrial production is insignificant while inflation decreases

[6]For most of the sample, each month generally has one or no auctions. Hence, the high-frequency surprises and, for those instances, monthly surprises are interchangeable.

significantly. These findings may be more relevant to understanding the impact of QT on the economy, which generates a slight increase in the unemployment rate but a relatively larger increase in inflation. When scaled appropriately, a 10-basis-point increase in long-term interest rates, measured using the forward rate from nine to ten years, generates a trough response in industrial production of 8.4 basis points and a peak response in the unemployment rate and the credit spread of 4 basis points and 14 basis points, respectively. The peak response in inflation is about 20 basis points.

The results are robust to using alternate measures of longer term interest rates, dropping the Great Recession (20007/12 to 2009/06) from the estimation sample, extending the sample till 2023/12, as well as constructing shocks to ten-year Treasury yields that control for any FOMC announcement on the same month as an auction for ten year Treasury notes and any FOMC announcement overlapping with auction days. Controlling for overlapping FOMC announcements increases the precision of estimated results.

The identification delivers statistically significant and economically relevant estimates describing the effectiveness of balance sheet policies. The results emphasize the borrowing-cost-driven transmission channel, independent of the usually studied monetary policy shock channel. Although intuitive, existing studies have been unable to demonstrate this link between balance sheet policies and economic activity empirically. Finally, in the process of constructing a suitable proxy for LSAP shocks, this article demonstrates the impact of auction days on financial markets, especially the term premium and important measures of borrowing costs in the economy.

Relation to existing studies: This article is broadly related to three strands of studies. The first group of studies examine the impact of LSAPs on interest rates using an event study approach, see for instance Gagnon, Raskin, Remache, and Sack (2011), Joyce, Lasaosa, Stevens, and Tong (2011), Krishnamurthy and Vissing-Jorgensen (2011) and Altavilla, Carboni, and Motto (2021) among others. These studies decompose the various channels through which interest rates might be impacted via asset purchase announcements by central banks. Swanson (2021) constructs a time-series of 'LSAP' shocks[7] using high-frequency identification around FOMC meetings and evaluates the impact on asset prices and interest rates as well. While, this approach is effective in summarizing the high-frequency impact of asset purchases on financial markets, they do not empirically establish the transmission of these interest rate changes to real activity.

The second group of studies examine the impact of unconventional monetary pol-

[7]Swanson (2021) extends the framework in Gurkaynak et al. (2005) to separately identify surprise changes in the federal funds rate, forward guidance, and large-scale asset purchases (LSAPs) for each FOMC announcement from July 1991 to June 2019. The LSAP factor measures surprise movements in the longer term interest rates with zero effects on federal funds rate and minimized to have zero impact on interest rates before 2009.

icy on economic activity in the U.S. using high-frequency identification in a structural vector auto regression (VAR) model. The most closely related in this group is Miranda-Agrippino and Ricco (2023) and Swanson (2024). Swanson (2024) finds very weak evidence supporting the effectiveness of these policies in stimulating or restraining economic activity, while the findings in Miranda-Agrippino and Ricco (2023) are counterintuitive for LSAP policies. A disadvantage of these studies is that the sample used for identifying LSAP shocks begin 2009 onward. The identification and restricted sample size often deliver ambiguous evidence regarding the impact of quantitative easing and tightening on economic activity.

This article circumvents these challenges imposed by the restricted sample size and identification by providing a new way to estimate the effects of balance sheet expansions and normalization policies on economic activity, focusing on the transmission mechanism. The identification is related to the approach in Ray, Droste, and Gorodnichenko (2024). Instead of measuring shocks to LSAP-related policies by examining the surprise component of interest rates (longer term) and relevant asset prices around a tight window bracketing FOMC announcements orthogonalized to shocks to the short-term federal funds rate and forward guidance, I focus on surprise movements of yields underlying the ten-year Treasury-note futures around U.S. Treasury Auctions. Ray, Droste, and Gorodnichenko (2024) also theoretically explore the transmission of QE/QT in a preferred habitat model following Vayanos and Vila (2021). In relation to how the empirical findings relate to the theoretical evidence in Ray et al. (2024), a QT shock in their framework, generates a decline in real activity. A QT shock however, does not create substantial downward pressure on inflation. In my empirical findings, real activity declines mildly, however, this is accompanied by an increase in CPI inflation.

The rest of the article is organized as follows. Section 2 discusses the choice to focus on ten-year zero coupon Treasury security. Section 3 describes the structure of U.S. Treasury Auctions and extracting surprises to the yields of ten-year Treasury-note futures around a thirty-minute window bracketing the closure of U.S. Treasury auctions. Section 4 discusses how to disentangle the impact of shocks to longer run interest rates from monetary policy shocks to the level and path of the federal funds rate. Section 5 presents the structural VAR model used to estimate the impact of shocks to the ten-year yield which mimics QE/QT shocks and Section 6 discusses the results of the estimation. Section 7 examines robustness of results and Section 8 concludes.

2 Importance of the ten-year Treasury note

The U.S. government guarantees Treasury securities, which are considered a risk-free benchmark for various assets in financial markets both in the U.S. and in the context of global financial markets. The ten-year Treasury security warrants special attention for the entire range of Treasury securities since key borrowing costs, for households and firms alike, use the yield on the ten-year Treasury as the relevant risk-free rate. Therefore, changes in the ten-year yield directly impact household and firm activity via this link. Figure 1 illustrates this feature. Alongside playing a central role in financial markets as

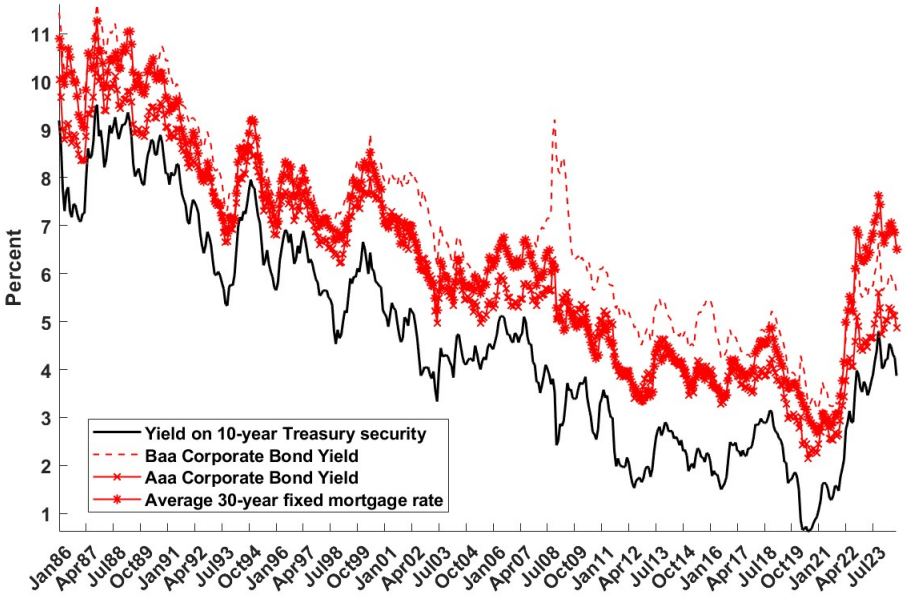


Figure 1: Borrowing costs in the economy for households as well as firms benchmarked to the yield on the ten-year Treasury security as the risk-free rate.

the benchmark risk-free rate, securities with maturity exceeding five years constituted the lion's share of the Treasury purchases during the Fed's LSAP programs. The first round of Large-Scale Asset Purchases (QE1) for instance involved the purchase of $300 billion in longer-term Treasury securities, with maturities greater than five years accounting for about 50% of the volume, while the second round (QE2) involved the purchase of $600 billion of longer-term Treasury securities. The ten-year Treasury is a well-representative of these purchases. Moreover, the effective duration of several longer-term assets purchased as part of the LSAP programs is closer to the 10-year benchmark. For instance, the duration on a 30-year MBS is around 7 years, more comparable to a 10-year Treasury (Krishnamurthy and Vissing-Jorgensen, 2011).

Most importantly, the market for ten-year T-notes and futures is one of most liquid

globally allowing accurate measurements of expectations about ten-year yields feasible. Therefore, in measuring longer term interests that were central to the implementation of LSAPs I focus exclusively on the ten-year zero-coupon Treasury security.

3 Treasury auctions and isolating unforeseen variations in ten-year Treasury yields

The U.S. federal government finances its operations primarily via taxes and by selling securities of varying maturities ranging from as short as four weeks to as long as thirty years. TreasuryDirect facilitates the purchase of Treasury securities. The schedule of Treasury securities auctions is released at the Treasury's Quarterly Refunding press conference, usually held on the first Wednesday of February, May, August, and November. The announcement precedes the auction by several days, for example, auctions for the 10-year security; initial offerings are announced in the first half of the month, with the auction day in the second week of the month. Auctions and auction announcements are usually separated by five to seven days. Additionally, the six months ahead tentative schedule for announcements and auctions are available each month.[8] The announcement also outlines the volume of Treasury securities in each category in advance. Press releases for the ten-year security types are available from August 5^{th}, 1998 onward; Figure 2 summarizes the frequency of U.S. Treasury auctions, and days between announcement and implementation dates.[9] Figure 2 shows 2009 onward, Treasury auctions are held once every month.

Auctions allow for two types of bids – competitive and noncompetitive bids. An auction market participant can submit a competitive bid(s), with each bid specifying the minimum yield at which they are prepared to buy a specific quantity of notes. Alternatively, they can also submit a noncompetitive bid specifying the amount of securities they wish to purchase at whatever price successful competitive bidders pay. Noncompetitive bids are limited to $10 million and bidding closes at 12.00 pm, Eastern time.[10] Competitive bidding, on the other hand, is limited to a maximum of 35% of the offering amount and closes at 1.00 pm Eastern time.[11]

The market for ten-year Treasury notes and associated futures is globally among the most liquid financial markets and movements in ten-year Treasury yields adequately re-

[8] For details see https://www.Treasurydirect.gov/auctions/when-auctions-happen/.

[9] https://www.Treasurydirect.gov/auctions/announcements-data-results/announcement-results-press-releases/

[10] See https://www.treasurydirect.gov/marketable-securities/treasury-notes/ for details.

[11] For more details see https://www.Treasurydirect.gov/auctions/announcements-data-results/announcement-results-press-releases/auction-results/,https://www.Treasurydirect.gov/auctions/how-auctions-work/.

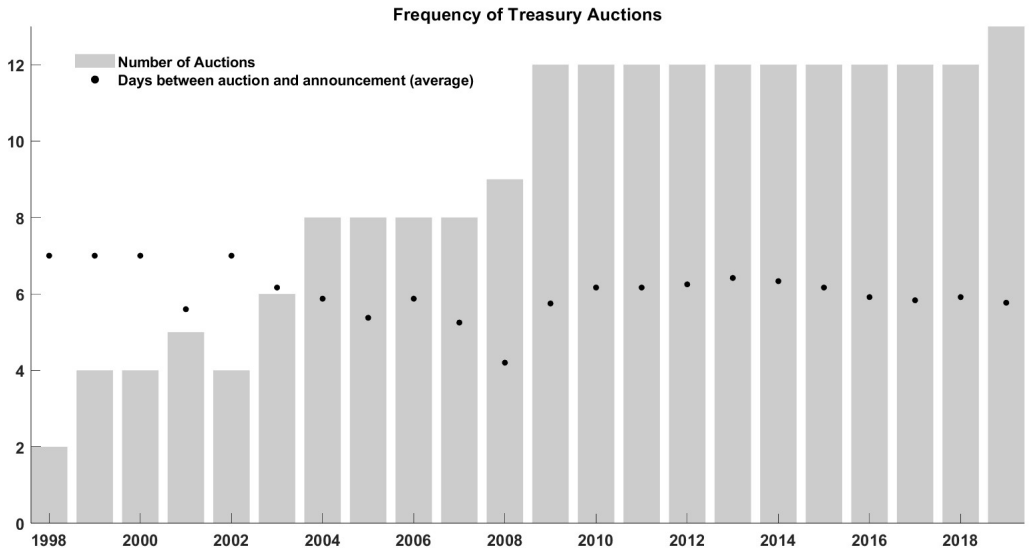


Figure 2: Documenting the frequency of U.S. Treasury auctions and average days between announcement and implementation of auctions for securities maturing in ten years. Since 2009, auctions have been scheduled every month. The figure excludes three additional auctions in 2008 for securities maturing in 6 years and 7 months (but classified as a ten-year security).

flect market expectations underlying ten-year Treasury yields.[12] The futures contracts used to construct surprises to the ten-year Treasury yields expire at the end of the current quarter. Given that the total quantity of securities available for auction is fixed and it is unlikely that any other relevant news is likely released around a tight 30 minute window bracketing the closure of auctions for the ten-year T-note, movements in ten-year futures yields around that window thus captures unforeseen changes in market expectations about the demand for the 10-year T-note security. Combined with this, if the ten-year Treasury is considered to be sufficiently representative of the class of longer term securities purchased by the Fed as a part of LSAP programs, the interpretation allows the surprises constructed using auction data to mimic LSAP shocks quantifying unforeseen changes in demand for Treasuries by the Fed.

I construct surprises to the yields on ten-year Treasury-note futures by calculating the change in yields around a thirty-minute window bracketing the closure of competitive bidding using tick-level data between between 12.50 pm and 1.20 pm Eastern time on the days auctions are implemented. Table 1 reports summary statistics of changes in yields between 1.20 pm and 12.50 pm for both auction and non-auction days. Table 1 among other differences shows that the surprises vary more on auction days relative to non-auction days. Summary statistics contrasting auction and non-auction days are

[12]See Baker, McPhail, and Tuckman (2020).

	Mean	Median	Standard Deviation	Minimum	Maximum	Number of observations
Non-Auction days	0.00	0.00	0.92	-6.95	5.93	4356
Auction days	-0.22	-0.10	1.71	-7.86	5.12	198

Table 1: Summary Statistics (basis points) of changes in yields underlying 10-year Treasury futures calculated between 1.20 pm and 12.50 pm Eastern time on auction and non-auction days between 1998/08 and 2019/12.

consistent with what Ray et al. (2024) report for the ten-year Treasury security. Changes in yields on auction days between 1.20 pm and 12.50 pm are then scaled by the standard deviation, such that a one-standard-deviation surprise equates to approximately a 1.7 basis point change in yields. Figure 3 plots this scaled series below. In comparison, a one-standard deviation LSAP shock in Swanson (2024) generates a 5.4 bps increase in the ten-yield.

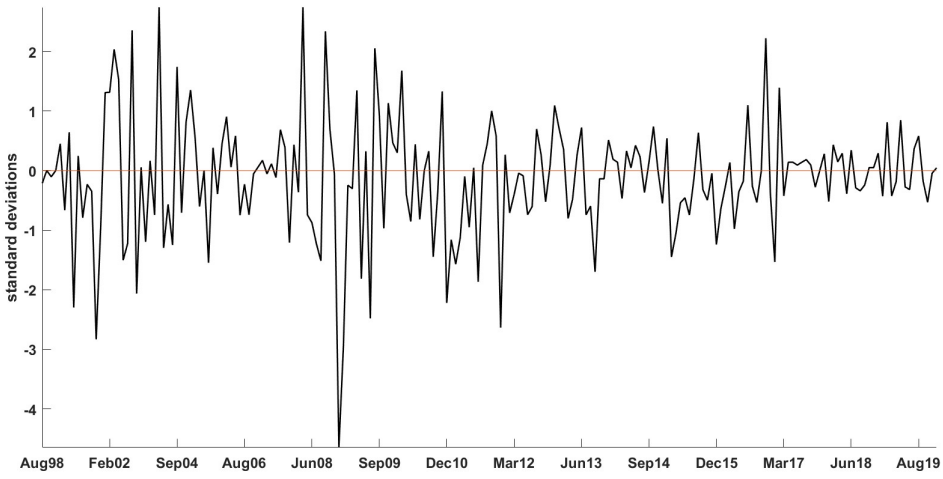


Figure 3: Surprises to yields on ten-year Treasury-note futures around a thirty-minute window bracketing the closure of U.S. Treasury auctions for ten-year securities. A one-standard-deviation surprise generates an increase in yields of about 1.7 basis points.

For the remainder of the article, I will either directly use this high-frequency measure of surprises or the measure cumulated monthly to evaluate its validity as an instrument quantifying exogenous variation in long-term Treasury yields.

3.1 The effect of ten-year Treasury-note futures changes on asset prices

To measure the effects of surprises on the yields underlying ten-year Treasury-note futures on asset prices, I estimate the following regression, which has been frequently estimated in the literature

$$\Delta y_t = \alpha_1 + \beta_1 Surprise_t + \epsilon_t^1, \quad \text{where } n \in 0, 1, 2, ..., 9 \tag{1}$$

with

$$\Delta y_t = y_t - y_{t-1}. \tag{2}$$

Here, $Surprise_t$ denotes the change in yield of the ten-year Treasury-note futures around a tight thirty window bracketing the closure of U.S. Treasury auctions of ten-year Treasury securities. Δy_t denotes the change in the relevant yield of assets (for example, one year Forward Rate going from nine to ten years). Δy_t is the difference between end-of-day yields on the day of the Treasury auction and the end-of-day yield on the day preceding the Treasury auction. If on the day preceding the auction, markets are closed, I use the end-of-day yield on the last day when markets are open before the auction for constructing Δy_t.ϵ_t quantifies other shocks to asset prices outside of surprises to ten-year Treasury-note futures.

The assets I consider consist of the one-, five-, and ten-year zero-coupon Treasury security and one-year forward rates going from one to two years, four to five years, and nine to ten years, and corporate bond yields – Moody's Aaa, Moody's Baa and the effective yield of the ICE BofA 7-10 Year US Corporate Index, respectively.[13] Zero-coupon Treasury yields and instantaneous forward rates are sourced from Gurkaynak, Sack, and Wright (2007) for zero-coupon Treasury securities. While the Moody's Seasoned Aaa and Baa Corporate Bond Yield measures the yield on corporate bonds that have the lowest default probability in the set of investment grade bonds, the ICE BofA 7-10 Year US Corporate Index, a subset of the ICE BofA US Corporate Master Index includes all dollar-denominate investment grade securities with a remaining term to maturity of greater than or equal to 7 years and less than 10 years.

Panels (a), (b) and (c) of Table 1 summarizes the estimated R^2 and F-statistics for the zero-coupon Treasury securities maturing in one, five, and ten years, one-year forward rates going from one to two, four to five, and nine to ten years, respectively, and corporate bond yields – Moody's AAA, Moody's BAA and the effective yield of the ICE BofA 7-10 Year US Corporate Index. Across these different interest rate measures, Table 2 shows

[13] See FRED, Federal Reserve Bank of St. Louis https://fred.stlouisfed.org/series/DBAA, https://fred.stlouisfed.org/series/DBAA, https://fred.stlouisfed.org/series/BAMLC4A0C710YEY for details.

	Panel (a) - Zero-coupon Treasury yields		
Maturity	1 year	5 years	10 years
R^2	0.044	0.133	0.187
F-stat	9.16	30.32	45.64
	Panel (b) - Instantaneous forward rates		
Maturity	1 year	4 years	9 years
R^2	0.086	0.170	0.191
F-stat	18.66	40.68	46.70
	Panel (c) - Corporate Bond Yields		
	Moody's AAA Corporate Bond	Moody's BAA Corporate Bond	ICE BofA 7-10 Year US Corporate Index
R^2	0.125	0.15	0.188
F-stat	28.36	35.05	45.89

Table 2: Summarizing the impact of surprises to ten-year T-note futures on zero-coupon yields, forward rates and corporate bond yields. Surprises to ten-year Treasury-note futures have a stronger impact on yields at the medium to long run.

that surprises to yields of ten-year Treasury-note futures have a bigger impact on yields for assets whose maturity close to ten years, explaining about 19% of daily variation in the ten-year zero-coupon yield, the 9-year instantaneous forward rate and the yield on corporate bonds maturing in seven to ten years respectively.

To better understand the impact on interest rates across the maturity spectrum, I estimate equation (1) for zero-coupon Treasuries, with maturities between one and thirty years respectively. The explanatory power of surprises on ten-year T-note futures, around a thirty-minute window bracketing the closure of Treasury auctions for 10-year securities, as Table 3 shows, increases monotonically until about 15 years in the maturity space. Yields are responsive at both the very short end and the very long end, but the impact is largely concentrated on securities closer to the 10-year maturity mark. Table 3 shows that surprises around auction closure to ten-year Treasuries generate effects consistent with the preferred habitat theory in Vayanos and Vila (2021).

Explanatory power of surprises to 10-Year futures around U.S. Treasury Auctions on Zero-Coupon Yields

	Auction Days (10-year T-Notes)		Non-Auction Days (10-year T-Notes)	
Maturity	R^2	F-stat	R^2	F-stat
1	0.044	9.16	0.016	55.3
2	0.074	15.9	0.029	102.52
3	0.095	20.71	0.038	133.51
4	0.114	25.58	0.044	156.61
5	0.133	30.32	0.049	173.04
6	0.149	34.65	0.051	183.88
7	0.162	38.37	0.053	190.29
8	**0.173**	**41.41**	0.054	193.27
9	**0.181**	**43.82**	0.0541	193.64
10	**0.19**	**45.64**	0.0537	192.29
15	**0.194**	**47.61**	0.049	175.5
20	0.173	41.34	0.045	159.22
30	0.089	19.36	0.033	116.51

Table 3: Effects across the maturity spectrum. Surprises to ten-year T-note futures around a thirty-minute window bracketing the closure of Treasury auctions for 10-year year securities generates preferred habitat like effects on the yield curve.

To investigate the channel through which auction-day surprises to ten-year futures impact the yield curve, following Adrian, Crump, and Moench (2013), I decompose the

zero-coupon yields on an n-period security, $n \in (1, 10)$, into two components – the term premium and the risk-neutral yield. I separately evaluate the contribution attributed to the term premium and risk-neutral yields underlying the daily changes in yields around Treasury auctions by estimating equation (1) with these two components for each maturity. Panel (a) of Table 4 summarizes the total estimated impact of a one-standard deviation (1.7 basis points) change in yields of ten-year futures around a thirty-minute window bracketing auction closure. Panels (b) and (c) report the same for the term premium and the risk-neutral yields, respectively.

	Impact of surprises to 10-year futures around U.S. Treasury Auctions on Zero-Coupon Yields (%)									
Maturity	1	2	3	4	5	6	7	8	9	10
	Total Effect (%)									
β_1	0.007	0.012	0.016	0.019	0.021	0.022	0.024	0.025	0.025	0.026
t-stat	2.53	3.26	3.7	4	4.23	4.44	4.64	4.83	4.98	5.11
	Effect via the term premium (%)									
β_1	0.006	0.011	0.014	0.016	0.018	0.019	0.021	0.022	0.022	0.023
t-stat	3.92	5.13	5.63	5.59	5.47	5.4	5.36	5.31	5.28	5.25
	Effects via risk-neutral yields (%)									
β_1	0.001	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003
t-stat	0.35	0.52	0.65	0.77	0.87	0.96	1.02	1.08	1.12	1.16

Table 4: Summarizing the impact of surprises to ten-year T-note futures on zero-coupon yields, risk-neutral yields and term premiums. Surprises to ten-year Treasury-note futures constructed around a thirty-minute bracketing the closure of Treasury auctions largely impacts zero-coupon yields via the term premium component. The impact on risk-neutral yields across the maturity spectrum is negligible.

When decomposing the effects into risk-neutral yields and the term premium, Panel (b) of Table 4 shows that the explanatory power of surprises to 10-year T-Note futures around auction closure mainly operates through the term premium. The term premium accounts for almost 90% of the change in yields for the ten-year Treasury. Given that the expected path of interest rates is pinned down by monetary policy, Panel (c) of Table 4, summarizing that the explanatory power of surprises to 10-year T-Note futures for

risk-neutral yields, shows little or no influence.

Tables 2 - 4 thus show that surprises in yields underlying 10-year T-Note futures around a thirty-minute window bracketing the closure of auctions of 10-year T-Notes have significant explanatory power for Treasury securities and corporate bonds – with the effect being larger for maturities closer to the 10-year mark. Moreover, changes in the term premium essentially drive this explanatory power.

Shorter-term business cycle fluctuations do not influence the schedule or implementation of auctions, and auctions operate independently of the dual mandate, unlike monetary policy. Moreover, the auction schedule is released several days ahead of auction day, allowing markets to fully react to information regarding the auction schedule, volume of securities up for purchase, or other economic news that might be released prior to the auction day. Moreover, since surprises are identified around a tight thirty-minute window, it is unlikely that any other news releases in that short time frame. Given these features, this approach isolates true surprises to longer-run interest rates at a daily frequency. Finally, since the supply of securities is fixed, the extracted surprises resemble a demand shock for ten-year Treasuries and, in the process, mimic high-frequency shocks via balance sheet policies.

4 Measure of longer-term interest rates orthogonal to 'usual' monetary policy shocks

At a daily frequency, given the nature of identification, the impact of surprises on interest rates identified via this approach around the closure of auctions are easily distinguishable from monetary policy shocks. However, when surprises are examined at a monthly level to develop an instrument to study the impact on macroeconomic variables, it might be difficult to exclusively extract the effect attributed to surprises to longer-run interest rates since FOMC announcements and Treasury auctions can happen within the same month.

As shown in Swanson (2021), there are three dimensions underlying monetary policy shocks – shocks to the level of the federal funds rate, shocks to the path of the federal funds rate, and shocks via LSAPs. While shocks to LSAPs examine the surprise component of longer-term treasuries around FOMC announcements and by construction exclusively impacts the longer end of the yield curve, various studies have shown that both shocks to the level and the path of the federal funds rate affect the yield curve at the shorter and longer end. I next tackle these issues by one by one.

To isolate variation in the ten-year yield driven exclusively by shocks to the longer-term interest rate bracketing the closure of U.S. Treasury auctions and independent of

shocks to the level and path of the federal funds rate, I do the following. I express the yield on the ten-year zero-coupon security, $y_t(10)$, as an average of one-year continuously compounded forward rates (going from zero to one year to nine to ten years) following Gurkaynak et al. (2007) such that

$$y_t(10) = \frac{1}{10}\sum_{i=1}^{10} f_t(i,1). \tag{3}$$

Here, $f(i,1)\ \forall i \in [0,9]$ is the one-year continuously compounded forward rate going from i to $i+1$ years. Appendix A presents the details underlying the derivation equation (3). Decomposing longer-term yields using equation (3) helps distinguish the impact of shorter-term factors (related to cyclical fluctuations and monetary policy expectations) from longer-term factors (such as inflation and economic growth expectations) on the yield underlying the ten-year zero-coupon Treasury security. I use Equation (3) to isolate forward rate components of the yield on the 10-year zero coupon rate, which are sensitive to monetary policy shocks around FOMC announcements versus shocks to ten-year T-note futures around Treasury auctions. Figure 4 plots the yield on the ten-year zero-coupon Treasury security into constituent forward rates and shows how the shorter term forward rates are more constrained by the factors determining the conduct of monetary policy.

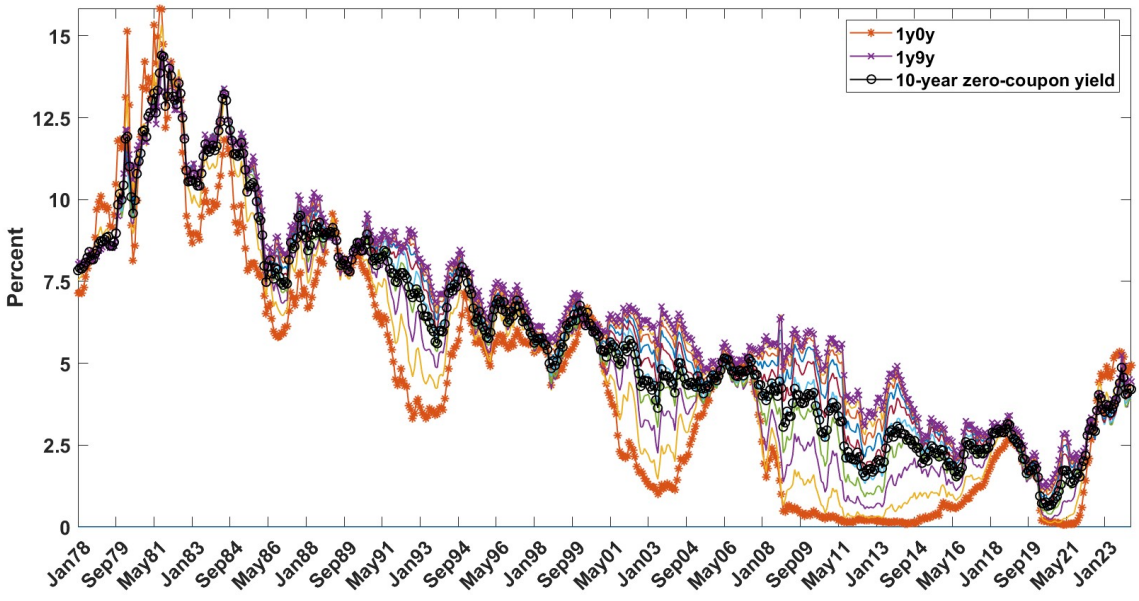


Figure 4: Decomposing the yield on the ten-year zero-coupon Treasury security into constituent forward rates distinguishing the influence of short-term, medium-term and longer-term factors.

Specification 1: To evaluate the impact of monetary policy shocks on forward rates, I estimate

$$\Delta f_t(i,1) = \alpha_2 + \beta_2 MPS_t + \epsilon_t^2, \quad \text{where } i \in 0,1,2,...,9 \tag{4}$$

with

$$\Delta f_t(i,1) = f_t(i,1) - f_{t-1}(i,1). \tag{5}$$

$f_t(i,1)$ is the one-year continuously compounded forward rate going from i to $i+1$ years. MPS_t is a measure of monetary policy shocks. I calculate the sequence of forward rates, $f_t(i,1)$ with $i \in [0,9]$ using data on zero-coupon yields constructed in Gurkaynak, Sack, and Wright (2007). As mentioned before, this data is available daily. High-frequency changes $\Delta f_t(i,1)$ are thus constructed by taking the difference between end-of-day yields on the day of the announcement and the end-of-day yield on the day preceding the announcement.

I measure monetary policy shocks (MPS_t) in equation (4) using high-frequency changes in the interest rate around a tight thirty-minute window bracketing FOMC announcements (along the lines of Gurkaynak et al. (2005), Gertler and Karadi (2015), Nakamura and Steinsson (2018), Miranda-Agrippino and Ricco (2021), Swanson (2021)). Specifically, I use the measure constructed in Bauer and Swanson (2023a). The measure in Bauer and Swanson (2023a), similar to Nakamura and Steinsson (2018), is constructed as the first principal component of Treasury futures and Eurodollar futures out to a horizon of one year. The measure thus captures shocks to both the level and the path of the federal funds rate. Furthermore, Bauer and Swanson (2023a) orthogonalize this measure to relevant non-monetary news to eliminate biases due to 'Fed response to news channel'. Panel (a) of Table 2 reports these results.

Specification 2: To contrast with the impact of surprises to ten-year T-note futures bracketing Treasury auctions, I estimate

$$\Delta f_t(i,1) = \alpha_3 + \beta_3 Surprise_t + \epsilon_t^3, \quad \text{where } i \in 0,1,2,...,9. \tag{6}$$

where $Surprise_t$ denotes the changes in yields of ten-year T-note futures around the thirty-minute bracketing the closure of Treasury auctions for ten-year T-notes. This is the baseline and Panel (b) of Table 2 reports these results.

Specification 3: To contrast with findings on non-auction days, I re-estimate equation (6) using changes in yields on 10-year T-note futures between 1.20 pm and 12.50 pm Eastern time on non-auction days and changes in end-of-day yields of forward rates on non-auction days as well. Panel (c) of Table 5 reports these results.

Monetary policy shocks account for a significant portion of the variability underlying forward rates at the shorter end, with these effects becoming negligible for forward rates

	One-year Forward Rate									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
	Panel (a) - Explanatory power of monetary policy shocks									
R^2	0.244	0.214	0.141	0.086	0.049	0.026	0.013	0.005	0.002	**0.0004**
F-stat	103.57	87.64	52.5	30.15	16.54	8.55	4.1	1.7	0.62	**0.14**
	Panel (b) - Explanatory power of surprises to 10-year futures on auction days (10-year T-Notes)									
R^2	0.044	0.086	0.115	0.146	0.17	0.186	0.194	0.197	0.195	**0.190**
F-stat	9.16	18.7	25.74	33.86	40.55	45.16	47.73	48.5	48.09	**46.51**
	Panel (c): Explanatory power of surprises to 10-year futures on non-auction days (10-year T-notes)									
R^2	0.016	0.035	0.047	0.053	0.054	0.053	0.049	0.045	0.041	**0.0377**
F-stat	55.3	123.17	166.25	189.61	194.79	188.18	175.84	161.11	145.86	**132.78**

Table 5: R^2 and F-statistic of the regression of forward rates on the instrument capturing surprises to the 10-year Treasury futures yields. Disentangling the impact of monetary policy shocks on the components of the ten-year zero coupon security yield.

ranging from six to seven years and insignificant for forward rates extending from seven to eight years and beyond. Shocks to ten-year futures, on the other hand, impact the shorter end of the yield curve, but the effects are quantitatively smaller, with the explanatory power increasing as we approach the longer end of the yield curve. The estimated impact on the forward rate going from nine to ten years has been highlighted in bold to compare these effects. Decomposing the ten-year zero-coupon yield curve into the constituent forward rates thus confirms that shocks to ten-year Treasury-note futures are relevant for the dynamics of the longer end of the yield curve. While monetary policy shocks impact the ten-year zero-coupon security, they do so only for forward rates in the short and medium terms.

Specification 4: Disentangling impact attributed to QE/QT announcements on same days as auctions Another point of concern in examining the validity of the instrument in driving high-frequency variation in longer-term yields is the potential for QE/QT-related FOMC announcements to occur on the same day as the auction. In this case, the effects attributed to surprises on the yields of ten-year T-note futures might be driven by those QE/QT news releases/announcements. Between 1998/08 and 2019/12, there are

seven dates on which U.S. Treasury auctions for 10-year securities overlap with FOMC announcements. The overlapping FOMC announcements not only include the QE/QT related monetary policy shocks but also shocks to the level and path of the federal funds rate that might have occurred on those days. These dates are as follows 6/11/2002, 10/11/2004, 8/10/2008, 12/08/2009, 13/12/2011, 13/03/2012, 12/12/2012. To account for this overlap, when I regress forward yields on estimated surprises to ten-year Treasury-note futures around auctions, I drop for these dates from the estimation.

$$\Delta f_t(i,1) = \alpha + \beta_4 Surprise_t \epsilon_t^4, \quad \text{where } i \in 0,1,2,...,9 \tag{7}$$

The measure of monetary policy shocks in Bauer and Swanson (2023a) quantifies the two dimensions: shocks to the level and path of the federal funds rate, which describe monetary policy shocks; hence, by construction, we do not need to control for shocks to LSAPs. Table 6 below compares the estimates from equation (4) with estimates from equation (7). After dropping for these dates overlapping with auctions, the explanatory power of the proposed instrument decreases; however, the explanatory power of shocks to ten-year Treasury-note futures remains relevant even after. Panel (b) of Table 6 reports these results.

Specification 5: Instead of dropping overlapping FOMC dates, the next specification controls for these dates with

$$\Delta f_t(i,1) = \alpha_5 + \beta_5 Surprise_t + \gamma_1 d_{1t} + \epsilon_t^5, \quad \text{where } i \in 0,1,2,...,9 \tag{8}$$

where $d_{1t} = 1$ for each of these 7 dates, 0 otherwise.Panel (c) of Table 6 reports these results. Controlling for these dates overlapping with auctions, compared to Specification 1, the R^2 statistic increases but only by a small amount (1%); Panel (c) of Table 6 reports these results.

Specification 6: Finally Specification 6 controls for all FOMC announcements occurring in the same month as the auction for 10-year Treasury securities and I estimate

$$\Delta f_t(i,1) = \alpha_6 + \beta_6 Surprise_t + \gamma_2 d_{2,t} + \epsilon_t^6, \quad \text{where } i \in 0,1,2,...,9$$

where $d_{2,t} = 1$ for all months having FOMC announcements, 0 otherwise. Panel (d) of Table 6 reports these results. Table 6 shows that the explanatory power across Specifications 5 and 6 is comparable to to what I estimate for the baseline scenario in equation (6).

Across these various specifications, the explanatory power of surprises to 10-year T-note futures for longer-term forward rates is largely unchanged. The results in Tables 2

- 6 suggest that forward rates at the longer end of the 10-year maturity spectrum, such as the forward rate going from nine to ten years, represent measures of long term term interest rates which are very responsive to shocks to the ten-year yield and simultaneously unaffected by monetary policy shocks.

Table 7 presents detailed estimates of regression coefficients and R^2 for Specification 6. Table 7 shows that for longer-term forward rates surprises in Treasury futures yields around auction closure generate quantitatively larger and significant movements relative to FOMC announcements in the same month. A one standard deviation positive surprise to ten-year yields around auction closure increases the forward rate going from nine to ten years by 3.2 basis points.

Finally, to illustrate the impact on forward rate term premiums, I construct risk-neutral forward rates using and evaluate the forward rate term premium at each horizon, by subtracting the risk-neutral forward rates from market-implied forward rates, both constructed using equation (21). Table 8 reports the findings for risk-neutral forward rates and forward rate term premiums for auction and non-auction days. Table 8 reinforces the fact that the impact of shocks to longer term interest rates around auction closure operates via changes in term premiums. The results in Tables 2 - 8 suggest that if we go far out at the longer end of the forward rate yield curve underlying the ten-year zero coupon yield, we can isolate a measure of longer term interest rate that is unaffected by monetary policy shocks but sensitive to shocks driving longer term interest rates. When estimating the macroeconomic effects of shocks to balance sheet policies, mimicked by shocks to longer-term interest rates, the forward rate from nine to ten years thus serves as a measure of longer-term interest rates.

5 Empirical Framework

Sections 2-3 explore an alternative approach to identifying shocks capturing the balance sheet expansion and contraction by Fed. This approach relies on constructing shocks to longer-term interest rate which mimic LSAP shocks. Next, I estimate the impact of shocks to LSAPs using this alternative approach on economic activity by estimating a monthly VAR model and identify shocks to longer-term interest rate via high-frequency methods.

Structural VAR model I calculate the impact of shocks to long term interest rates on macroeconomic activity in two steps. First, I estimate a reduced form VAR model using Bayesian methods with

$$y_t = \alpha + B(L)y_{t-1} + u_t. \tag{9}$$

	One-year Forward Rate									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
	Panel (a) - Explanatory power of surprises to 10-year futures around U.S. Treasury Auctions									
R^2	0.044	0.086	0.115	0.146	0.17	0.186	0.194	0.197	0.195	**0.19**
F-stat	9.16	18.7	25.74	33.86	40.55	45.16	47.73	48.5	48.09	**46.51**
	Panel (b) - Explanatory power of surprises to 10-year futures around U.S. Treasury Auctions **dropping overlapping FOMC meeting days**									
R^2	0.032	0.086	0.104	0.124	0.139	0.148	0.152	0.152	0.151	**0.149**
F-stat	6.37	17.86	22.19	27	30.73	33.08	34.14	34.31	34.01	**33.37**
	Panel (c) - Explanatory power of surprises to 10-year futures around U.S. Treasury Auctions **controlling overlapping FOMC meeting days**									
R^2	0.056	0.114	0.146	0.177	0.199	0.212	0.217	0.215	0.209	**0.201**
F-stat	5.79	12.63	16.86	21.23	24.53	26.55	27.29	26.97	26.09	**24.75**
	Panel (d) - Explanatory power of surprises to 10-year futures around U.S. Treasury Auction **controlling FOMC meeting days same month**									
R^2	0.058	0.12	0.157	0.179	0.196	0.206	0.209	0.206	0.202	0.197
F-stat	6.06	13.42	18.36	21.47	23.99	25.55	25.97	25.61	24.93	24.21

Table 6: R^2 and F-statistic of the regression of forward rates on the instrument capturing surprises to the 10-year Treasury futures yields across Specifications 2,4,5 and 6 respectively. Controlling for FOMC announcements on the same day and same month as auctions does not change the explanatory power significantly relative to the baseline specification (Panel (a)). Even if overlapping FOMC dates are dropped, surprises around a thirty-minute window bracketing the closure of Treasury auction for 10-year T-note securities have sufficient explanatory power.

Here, y_t is the vector of endogenous variable where, $\dim(y_t) = n \times 1$. $B(L)$ is a polynomial in the lag operator and u_t is the vector of reduced form shocks with $Var(u_t) = \Omega$. I also assume that the system in equation (9) is invertible. Let ϵ_t be the vector of structural shocks such that $dim(\epsilon_t) = n$ and $Var(\epsilon_t) = \mathcal{I}$. Consistent with studies examining the effects of monetary policy shocks on the economy (see for instance, Gertler and Karadi (2015), Ramey (2016), Miranda-Agrippino and Ricco (2021), Bauer and Swanson (2023b), among others) I assume that the economy is driven by a set of n structural shocks, such

	One-year Forward Rate									
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
constant	-0.005	-0.015	-0.019	-0.017	-0.012	-0.008	-0.004	0	0.002	0.004
t-stat	-1.55	-2.61	-2.73	-2.29	-1.69	-1.06	-0.51	-0.06	0.27	0.52
β	0.007	0.016	0.022	0.026	0.028	0.029	0.031	0.031	0.032	**0.032**
t-stat	2.39	3.32	3.86	4.26	4.66	5	5.24	5.36	5.39	**5.38**
γ	0.01	0.025	0.029	0.028	0.025	0.021	0.018	0.016	0.014	**0.012**
t-stat	2.05	3.29	3.36	3.03	2.65	2.29	1.95	1.64	1.4	**1.21**
R^2	0.058	0.12	0.157	0.179	0.196	0.206	0.209	0.206	0.202	0.197
F-stat	6.06	13.42	18.36	21.47	23.99	25.55	25.97	25.61	24.93	24.21

Table 7: Detailed Regression Results, Specification 6 estimating $\Delta f_t(i,1) = \alpha_6 + \beta_6 Surprise_t + \gamma_2 d_{2,t} + \epsilon_t^6$, where $d_{2,t} = 1$ for FOMC announcements in the same month and 0 otherwise. The relative contribution of surprises to ten-year futures around the closure of Treasury auctions dominates FOMC announcements on the same month. A one-standard deviation change in $Surprise_t$ causes a 3.2 basis point change in longer-term forward rates (highlighted in bold). For short to medium forward rates FOMC announcements have significant and quantitatively comparable impact as longer term interest rate shocks measured by $Surprise_t$.

Panel (a) - Impact of surprises to 10-year futures around U.S. Treasury Auctions - One-year Forward Rates - Total Effect (%)

	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
R^2	0.007	0.016	0.022	0.026	0.028	0.029	0.031	0.031	0.032	0.032
F-stat	2.39	3.32	3.86	4.26	4.66	5	5.24	5.36	5.39	5.38

Panel (b) - Impact of surprises to 10-year futures around U.S. Treasury Auctions - Term premium

R^2	0.006	0.015	0.02	0.023	0.025	0.026	0.027	0.028	0.029	0.03
F-stat	3.93	5.49	5.29	4.96	4.95	5.02	5.03	5.01	4.99	4.97

Panel (c) - Impact of surprises to 10-year futures around U.S. Treasury Auctions - Risk-Neutral Zero-Coupon Yields (%)

R^2	0.001	0.002	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003
F-stat	0.24	0.41	0.64	0.86	1.04	1.18	1.28	1.35	1.39	1.43

Table 8: Summarizing the impact of surprises to ten-year T-note futures on one-year forward rates, one-year risk-neutral forward rates implied yields and one-year forward rate term premiums.

that

$$u_t = S\epsilon_t; \text{ where } \dim(S) = n \times n \tag{10}$$

and one of these n structural shocks is the shock to the long-run interest rate ϵ_t^{LR}. Without loss of generality, let ϵ_t^{LR} be ordered first such that the first column of S describes the impact effects of shocks to long-term interest rates.

Data and Estimation I estimate equation (9) with vector of endogenous variables $y = [FR_{1,(9,10)}, \ln CPI, \ln IP, UR, GZ, \ln S\&P, TB_1, TB_{10}, \text{BC}, \pi^e]$. Here, $FR_{1,(9,10)}$ is the one-year forward rate going from 9 to 10 years, CPI is the Consumer Price Index, IP is the Index of Industrial Production, GZ is the Gilchrist and Zakrajšek credit spread (Gilchrist and Zakrajšek (2012)), UR is the unemployment rate, S&P is the S&P stock market index, TB_1 is the yield on the one-year Treasury security, TB_{10} is the yield on the ten-year Treasury security. Finally, BC is a measure of expectations about future business conditions,[14] and π^e is a measure of inflation expectations. The sample for estimation begins 01/1978 since that is the earliest available data for the inflation expectations measured by the University of Michigan.[15] The CPI, industrial production, the credit spread and the stock market are standard inclusions in VAR models studying the impact of monetary policy (see for instance, Gertler and Karadi (2015), Jarociński and Karadi (2020), Bauer and Swanson (2023b) among other others). The one- and ten- year zero-coupon yields capture the short and longer ends of the yield curve. I also include measures of longer term expectations as changes in longer-term yields potentially impact expectations and real activity via the expectation channel. Equation (9) is estimated using monthly data between 01/1978 and 12/2019 using a lag length of 12. The estimation of equation (9) follows the Bayesian estimation methodology of Miranda-Agrippino and Ricco (2021). Miranda-Agrippino and Ricco (2021) implement the informative prior selection in Giannone, Lenza, and Primiceri (2015) to reduce estimation uncertainty stemming from large dimensional parameter space.

High-frequency identification The identification of the impact of the shocks to longer run interest rates on various dimensions of economic activity is achieved by using

[14]Business Conditions Expected During the Next 5 Years. Index constructed on the basis of responses to the following question: 'The question was: Looking ahead, which would you say is more likely – that in the country as a whole we'll have continuous good times during the next 5 years, or that we'll have periods of widespread unemployment or depression, or what?' for details see https://data.sca.isr.umich.edu/data-archive/mine.php

[15]Median expected price change next 12 months, Surveys of Consumers. For details, see https://fred.stlouisfed.org/series/MICH. For expectations about future prices, the median expected price change over the next 12 months is used instead of 5 years since the latter is available continuously at a monthly level since 1990/04.

the external instrument approach. Here, movements in the yields of ten-year Treasury future around a thirty-minute window bracketing the closure of U.S. Treasury auctions for ten-year notes is the external instrument for shocks to longer term interest rates, measured by the one-year forward rate going from 9 to 10 years. Let, z_t denote the external instrument defined above such that

$$E(z_t \epsilon_t^{LR}) \neq 0 \tag{11}$$

and

$$E(z_t \epsilon_t^{i}) = 0 \; \forall i \neq LR. \tag{12}$$

The strength of instrument at a monthly level is evaluated by calculating the Wald statistic, ζ_1 for the covariance between the instrument and the normalized variable following Montiel Olea et al. (2021) which delineates conditions guiding the boundlessness of the $(1-\alpha)\%$ confidence interval when $\zeta_1 > \chi^2_{(1-\alpha)}$. When calculating 90% confidence bands, $\chi^2_{(1-\alpha)} = 2.7055$. For all the specifications considered the criteria for a strong instrument is satisfied with all 10 endogenous variables and a lag-length of 12.

Exogeniety with respect to other structural shocks is achieved via the high-frequency identification technique as well as the fact the U.S. Treasury auctions are not driven by shorter term cyclical fluctuations. Finally, Table 9 reports the results of regressing surprises to the 10-year futures yields on monetary policy shocks, using monthly data. Table 9 shows that, at a monthly frequency, surprises around auctions are not impacted by monetary policy shocks. Movements in the yields of ten-year Treasury-note futures

constant (pval)	coefficient on monetary policy shock (pval)	F-statistic (pval)
-0.10	1.51	1.73
(0.06)	(0.19)	(0.19)

Table 9

is thus a valid external instrument for the monthly one-year forward rate going from 9 to 10 years.

6 Results: Impact of Balance Sheet Policies

I start by discussing the impact of balance sheet policies by examining a one-standard-deviation decrease in the longer end of the ten-year zero-coupon yield measured by the one-year forward rate going from 9 to 10 years. This exercise mimics the impact of a surprise balance sheet expansion. The VAR model in equation (9) is linear and the effects of a one-standard-deviation tightening is symmetric.

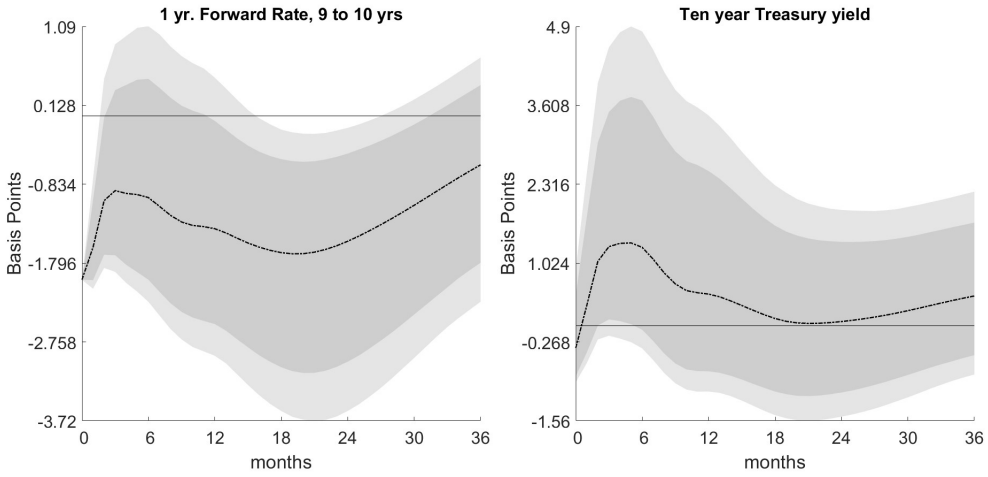


Figure 5: Impulse responses to a negative one-standard-deviation shock to the one-year Forward Rate going from 9 to 10 years and the yield on ten-year zero-coupon Treasury security. A negative one-standard-deviation shock to the one-year Forward Rate, going from 9 to 10 years, generates an impact decline of 2 basis points (0.02%). Shaded areas denote 90% (80%) percentile error bands.

A negative one-standard-deviation shock causes an impact decline of about 2 basis points in the one-year forward rate going from nine to ten years. Figures 5 - 9 plot the response of endogenous variables to this shock. On impact, the one-year forward rate, going from 9 to 10 years, declines with the impact of surprise easing persisting for several months. On the other hand, the response of the ten-year zero-coupon yield which meshes the impact of forward rates across the 10-year maturity spectrum, declines on impact but increases a in subsequent periods and is statistically insignificant for the most part.

The credit spread, shows a sharp and significant decline on impact and remains negative for up to 18 months after the shock. The more than proportionate decline in the credit spread in response to surprise easing is key as other papers exploring the impact of LSAPs fail to empirically establish this intuitive link (see, for instance, Swanson (2024), Miranda-Agrippino and Ricco (2023)).

Along with the credit spread, the S&P 500 increases sharply also, and the magnitude, when scaled appropriately to match the shock size, is comparable to what Jarociński and

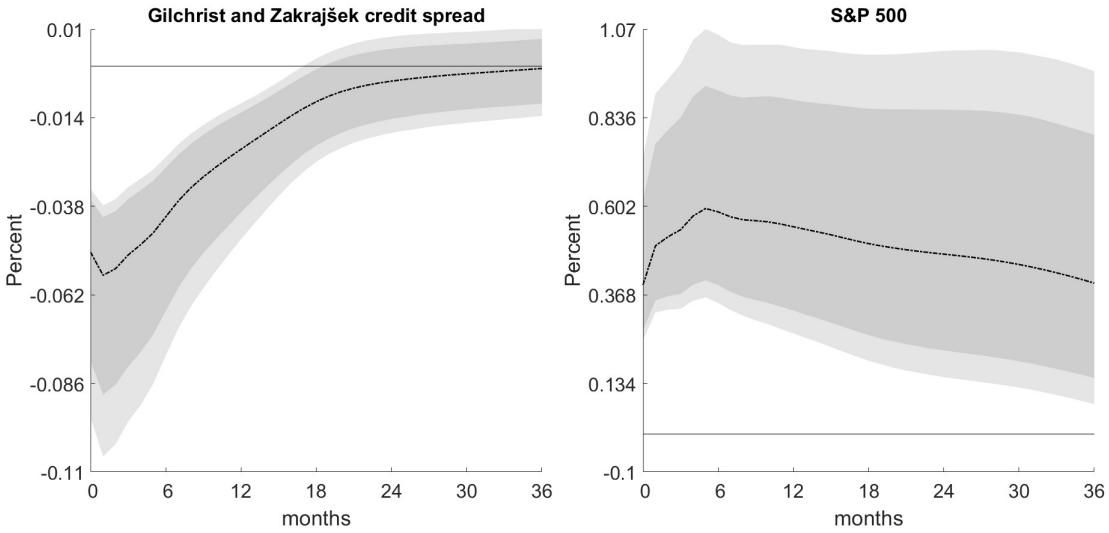


Figure 6: Impulse responses of the Gilchrist and Zakrajšek credit spread, the log of the S&P 500 and the NFCI to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Identification and estimation include the Great Recession. Shock identified using data between 01/1998 and 12/2019. Lighter (darker) Shaded areas denote 90% (80%) percentile error bands.

Karadi (2020) estimate when studying the impact of monetary policy shocks. Figure 10 shows that the increase in the stock market is in part driven by the sharp decline in credit spreads, which triggers a decline in total borrowing costs and spills over to improved stock market performance.

The sharp decline in credit spreads is accompanied by an increase in both the industrial production and the unemployment rate. In response to surprise balance sheet expansion, Industrial production increases a few months after the shock and remains elevated for several months following the shock. Unemployment rate on the other hand decreases on impact, this decline is persistent hitting a trough around 18 months. Inflation decreases on impact and similar to industrial production increases persistently thereafter. The increase is however, modest and largely insignificant. Figure 7 plots these results.

Figure 8 plots the responses of one-year ahead expectations about business conditions and inflation. In response to a surprise easing of longer-run interest rates, expectations about business conditions in the near future become optimistic. In line with industrial production, economic outlook improves with a hump-shaped response. Outlook about the expected price change declines sharply on impact but recovers in the periods following the shock. Finally, as the improvement in economic conditions gains strength, the one-year yield increases, but modestly in comparison to the increase in industrial production and decrease in the unemployment rate.

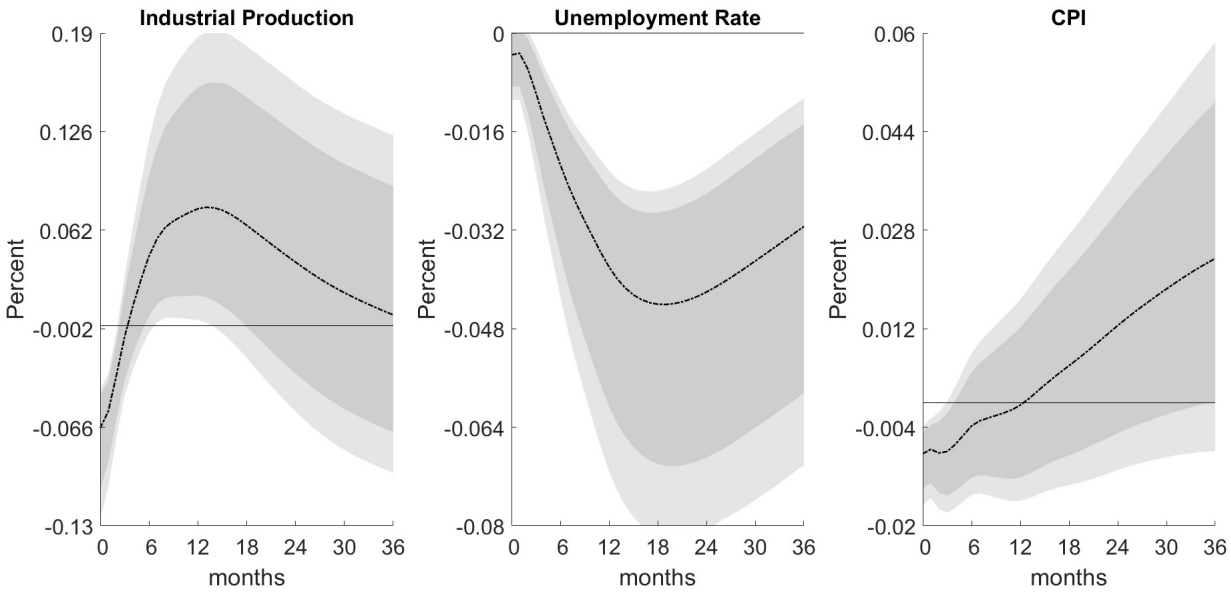


Figure 7: Impulse responses of the log of Industrial Production and the CPI to a one-standard-deviation shock to the one-year forward rate going from 9 to 10 years. Shock identified using data between 01/1998 and 12/2019. Lighter (darker) Shaded areas denote the 90% (80%) percentile error bands.

To highlight the importance of the borrowing cost channel of transmission underlying balance sheet policies, I conduct a counterfactual exercise. I estimate equation (9) as before, but when constructing impulse responses, I set the response of the credit spread to zero. Figure 10 plots the impulse responses of this counterfactual exercise along with the results in Figures 5 - 10. Figure 10 shows that when the borrowing cost channel is switched off, easing of longer-term interest rates no longer generates the significant improvement in economic activity as seen in Figures 5 - 10. Industrial production shows a persistent decline. The unemployment rate declines; however, it is significantly smaller than the baseline. The stock market improves, but the improvement is less persistent. Improvement in borrowing costs thus reinforces the improvement in stock market performance as well.

In this exercise, an LSAP shock is quantified by a surprise 2 basis point easing of longer term interest rates. When scaled appropriately, a 10-basis-point reduction in long-term interest rates, measured using the forward rate from nine to ten years, generates a peak response in industrial production of 38 basis points and a trough response in the unemployment rate and the credit spread of 22 basis points and 28 basis points, respectively. Figures 5 - 10 thus effectively demonstrate the impact of balance sheet policies on stimulating (restraining) economic activity highlighting the credit-channel of transmission.

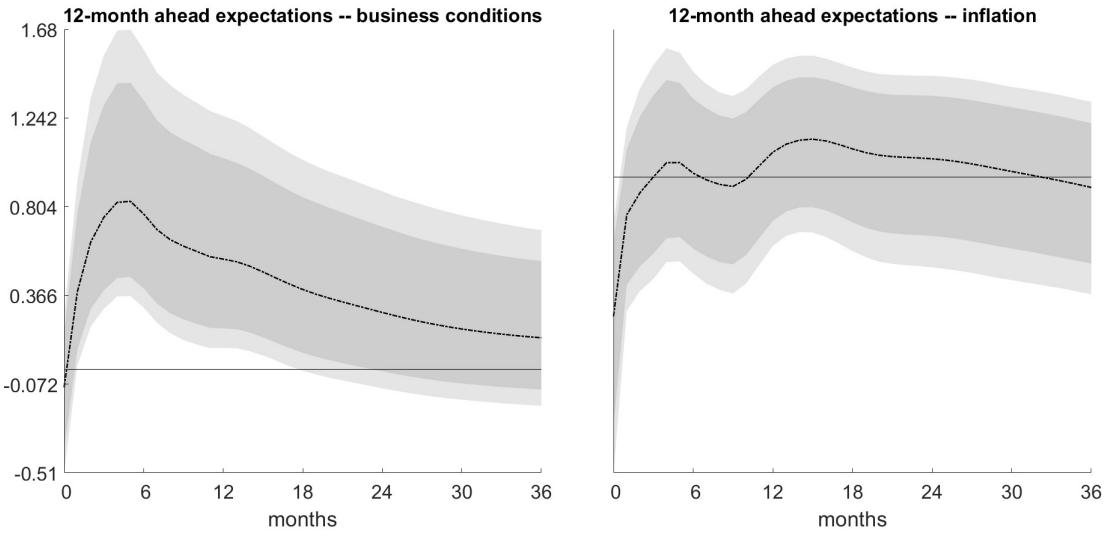


Figure 8: Impulse responses of the one-year ahead expectations about business conditions and the median expected price change in the next 12 months to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Shock identified using data between 01/1998 and 12/2019. Lighter (darker) Shaded areas denote the 90% (80%) percentile error bands.

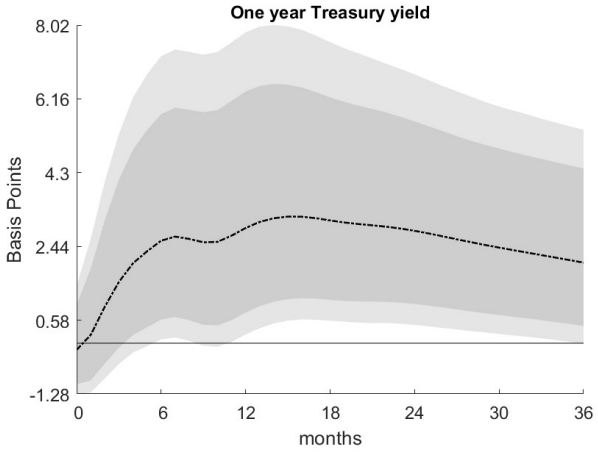


Figure 9: Impulse responses of the yield on the one-year Treasury security to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Shock identified using data between 01/1998 and 12/2019. Lighter (darker) Shaded areas denote the 90% (80%) percentile error bands.

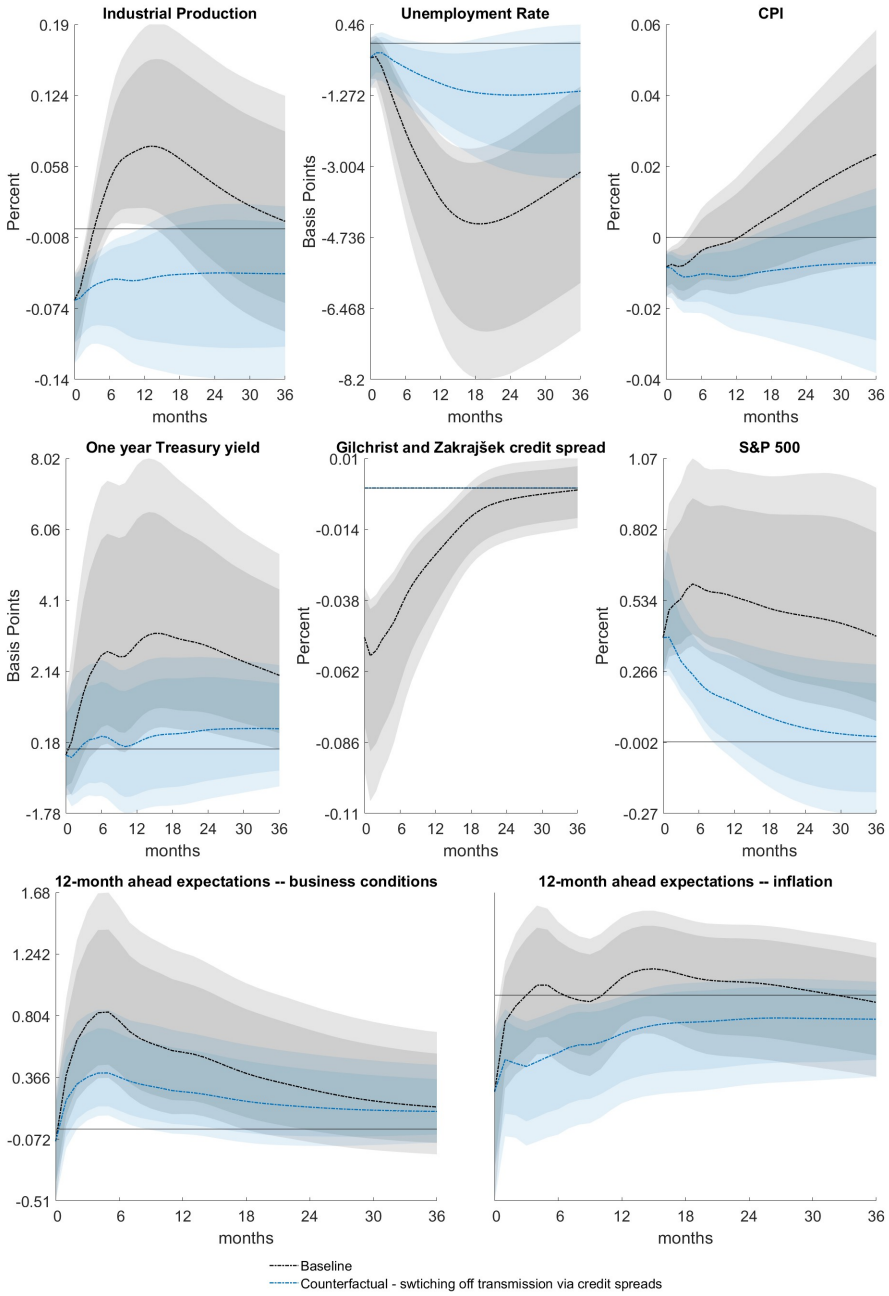


Figure 10: Counterfactual analysis –switching off the response of the credit spread: Impulse responses of the log of Industrial Production, log of the CPI, expectations about 12-months ahead business conditions and expectations about 12-month ahead inflation to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Light (dark) shaded areas denote 90% and 80% confidence bands.

6.1 Effectiveness of balance sheet policies when the federal funds rate is unconstrained

The VAR model in equation (9) is linear and predicts symmetric results for expansionary and contractionary shocks to longer term interest rates. Consequently, the impact of QE and QT are symmetric when these shocks mimic balance sheet expansion and normalization. However, the Fed conducts balance sheet normalization when the federal funds rate is no longer constrained. To evaluate the effectiveness of balance sheet normalization, I re-estimate equation (9) by dropping the periods when the federal funds rate is constrained by the ZLB (2009/01-and 2015/11).

Figure 11 shows that 1 standard-deviation contraction to longer run interest rates, generates a decline in credit spread and the unemployment rate as well as optimism about future outlook about business conditions. Quantitatively, the responses are smaller than what I report in Figures 5-9. The response of industrial production is however muted and the decline in inflation is significant and persistent. The accompanying decline in inflation expectation in conjunction with the response of inflation suggests that expansionary (contractionary) policies when the federal funds rate is unconstrained signals strongly about weaker (stronger) longer-term expectations about inflation and economic activity.

Figure 11 suggests that when the Fed conducts balance sheet normalization, the impact of economic activity is muted but credit spreads still increase with a more than proportionate pass-through of the increase in longer term interest rates. The stock market also declines significantly on impact and the impact is persistent. Additionally, QT is inflationary in the longer turn. This also aligns with the intention of normalization which is timed such that economic fundamentals and outlook is optimistic. When scaled appropriately, a 10-basis-point increase in long-term interest rates, measured using the forward rate from nine to ten years, generates a trough response in industrial production of 8.4 basis points and a peak response in the unemployment rate and the credit spread of 4 basis points and 14 basis points, respectively. The peak response in inflation is about 20 basis points.

This exercise also evaluates the potency of balance sheet policies as an independent policy tool. When these policies are undertaken by eliminating periods of economic distress the impact on economic activity is muted although financial markets still respond significantly to such policies.

7 Robustness Checks

This section evaluates the robustness of results by examining the impact of these policies by excluding the Great Recession from the sample, alternate measures of longer term

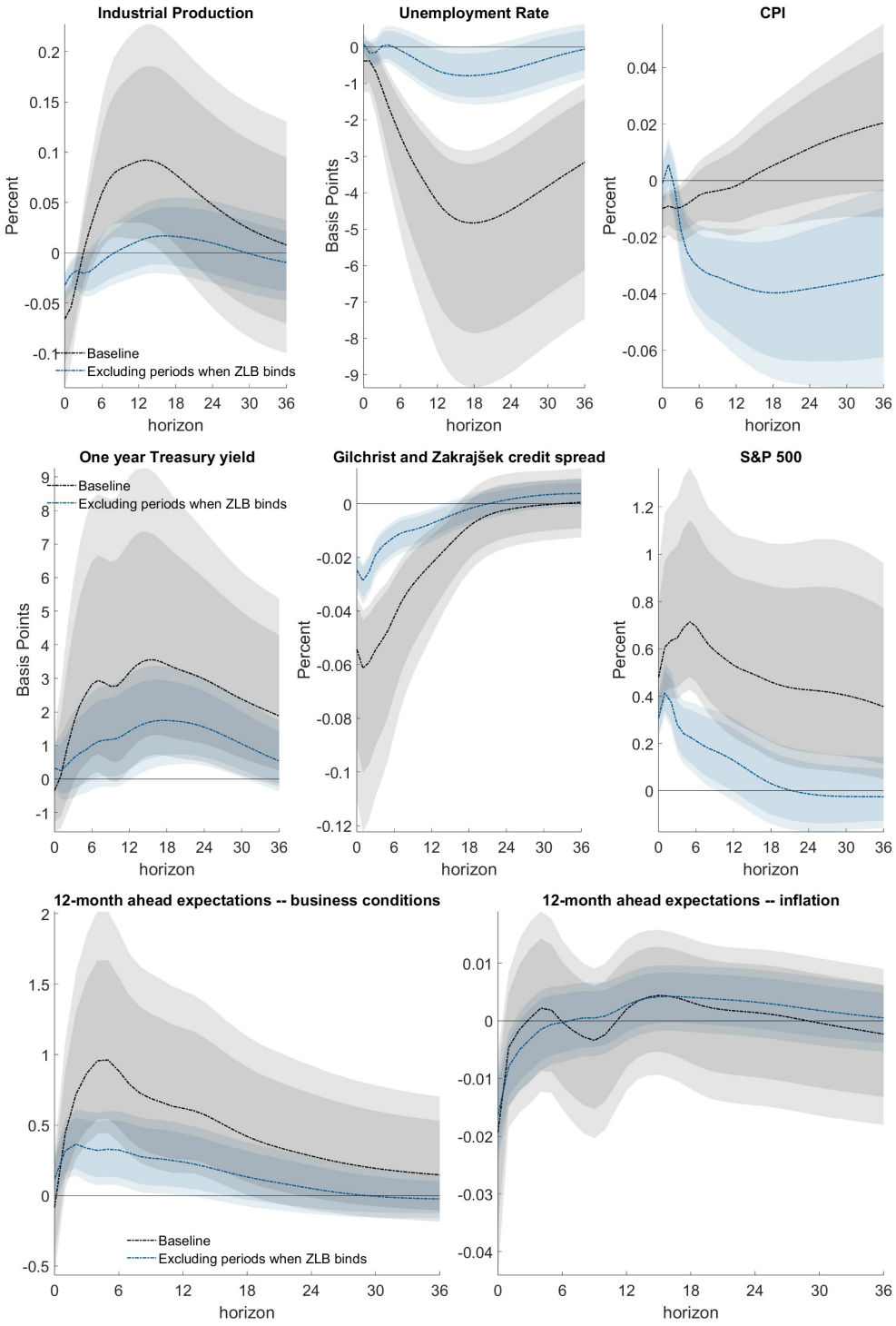


Figure 11: Effectiveness of balance sheet policies estimated by dropping periods when the policy instrument is unconstrained by the ZLB: Impulse responses of the log of Industrial Production, log of the CPI, expectations about 12-months ahead business conditions and expectations about 12-month ahead inflation to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Light (dark) shaded areas denote 90% and 80% confidence bands.

interest rates, constructing shocks to longer-term Treasuries by controlling for FOMC announcements in the same month and the same day and finally by extending the sample to 2023.

7.1 Dropping the Great Recession

Unconventional monetary policy via QE was implemented by the Fed in January 2009 after fully utilizing conventional tools in a deeply distressed economy. To evaluate the robustness of results, I estimate equation (9) by excluding the Great Recession from the sample (2007/12-2009/06). Figure 12 compares the responses obtained by dropping the Great Recession from the sample with the responses obtained from the baseline sample. When the Great Recession is excluded from the sample, a surprise easing via QE generates an immediate increase in industrial production and a decline in the unemployment rate on impact. The response of the credit spread is however muted, indicating that the decline in longer run interest rate is offset by the increase in borrowing costs, leaving the credit spread largely unaffected. The results also suggest that when episodes of extreme financial distress are eliminated, balance sheet policies can trigger a faster increase in economy activity.

Alternate measure of longer-term interest rates The analysis in the previous section use the one-year forward rate going from 9 to 10 years as a measure of longer term interest rates. The results however, are not specific to this measure. As evidenced in Tables 5 -7, monetary policy shocks only influence one-year forward rates composing the ten-year zero-coupon yield at a short to medium maturity with the explanatory power diminishing for forward rates around the 7 year maturity. To demonstrate the robustness of results to the measure of longer term interest rates, I re-estimate 9 using the on-year forward rate, going from 7 to 8 years. Figures 13 plots these responses in solid black lines.

Shocks controlling for FOMC announcements on the same month In the analysis so far, I instrument shocks to longer-term interest rates using standardized surprises to ten-year Treasury futures yields around a thirty minute window bracketing auction closure of ten-year Treasury securities. To check the robustness of results, I orthogonalize the instrument to the incidence of FOMC announcements on the same month as auctions. I regress high-frequency data on surprises extracted around auction closure on a dummy variable $d_{2,t}$ which equals 1 if there is an FOMC meeting on the same month as the auction and 0 otherwise and construct the orthogonalized measure of surprises to FOMC announcements ($Surprises_t^{\perp,m}$)

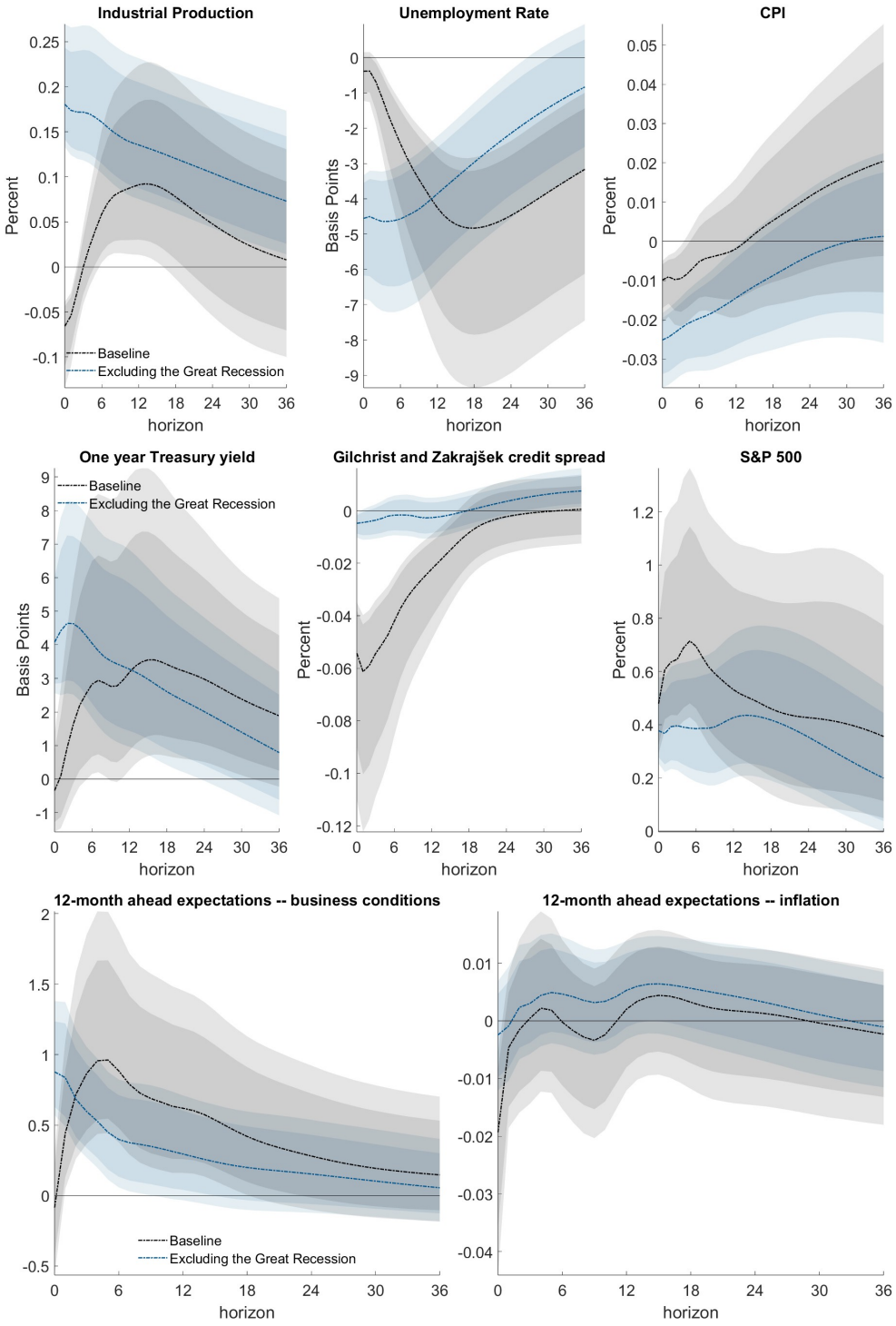


Figure 12: Effectiveness of balance sheet policies estimated by dropping the Great Recession: Impulse responses of the log of Industrial Production, log of the CPI, expectations about 12-months ahead business conditions and expectations about 12-month ahead inflation to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Light (dark) shaded areas denote 90% and 80% confidence bands.

$$Surprises_t = c + \delta d_{3,t} + \epsilon_t^{\perp,m} \quad \text{where } Surprises_t^{\perp,m} = \epsilon_t^{\perp,m}. \tag{13}$$

Figures 13 plots these responses in circled black lines.

Shocks controlling for FOMC announcements on the same day as auctions I orthogonalize the instrument to the incidence of FOMC announcements on the same days as auctions by regressing high-frequency data on surprises extracted around auction closure on a dummy variable $d_{2,t}$ which equals 1 if there is an FOMC meeting on the same as the auction and 0 otherwise and construct the orthogonalized measure of surprises to FOMC announcements ($Surprises_t^{\perp,d}$)

$$Surprises_t = c + \delta d_{3,t} + \epsilon_t^{\perp,d} \quad \text{where } Surprises_t^{\perp,d} = \epsilon_t^{\perp,d}. \tag{14}$$

Figures 13 plots these responses in crossed black lines.

Extended sample The data in the main analysis stops at 2019/12 prior to the incidence of the covid-19 pandemic, primarily to eliminate the influence various large scale fiscal and monetary interventions undertaken to mitigate the impact of the pandemic. As a robustness check, I re-estimate equation (9) using data between 1978/01 and 2023/12. Figures 13 plots these responses in starred black lines.

The findings for the QE shock in the extended sample are qualitatively consistent with what I estimate for the sample ending 2019/12 and the mean effects largely comparable across all variables except industrial production. While the response of the unemployment rate is significant, industrial production does not record a significant response for this extended sample. This could be due to various large scale fiscal and credit programs extended during the pandemic which are unaccounted for in the analysis.

8 Conclusion

Since the Great Recession, balance sheet expansion and normalization policies have become a standard constituent in policymakers' toolkit. However, empirical studies estimating the impact of these policies on macroeconomic activity have been restricted mainly to examining the high-frequency impact of these LSAP announcements on financial markets. This article presents an alternative approach to quantify the effects of LSAPs by measuring shocks to QT/QE via surprises to longer-term interest rates independent of 'non-LSAP-related monetary policy shocks'.

Treasury auctions of longer-term securities provide a natural way to isolate exogenous changes in longer-term interest rates that are orthogonal to conventional monetary policy

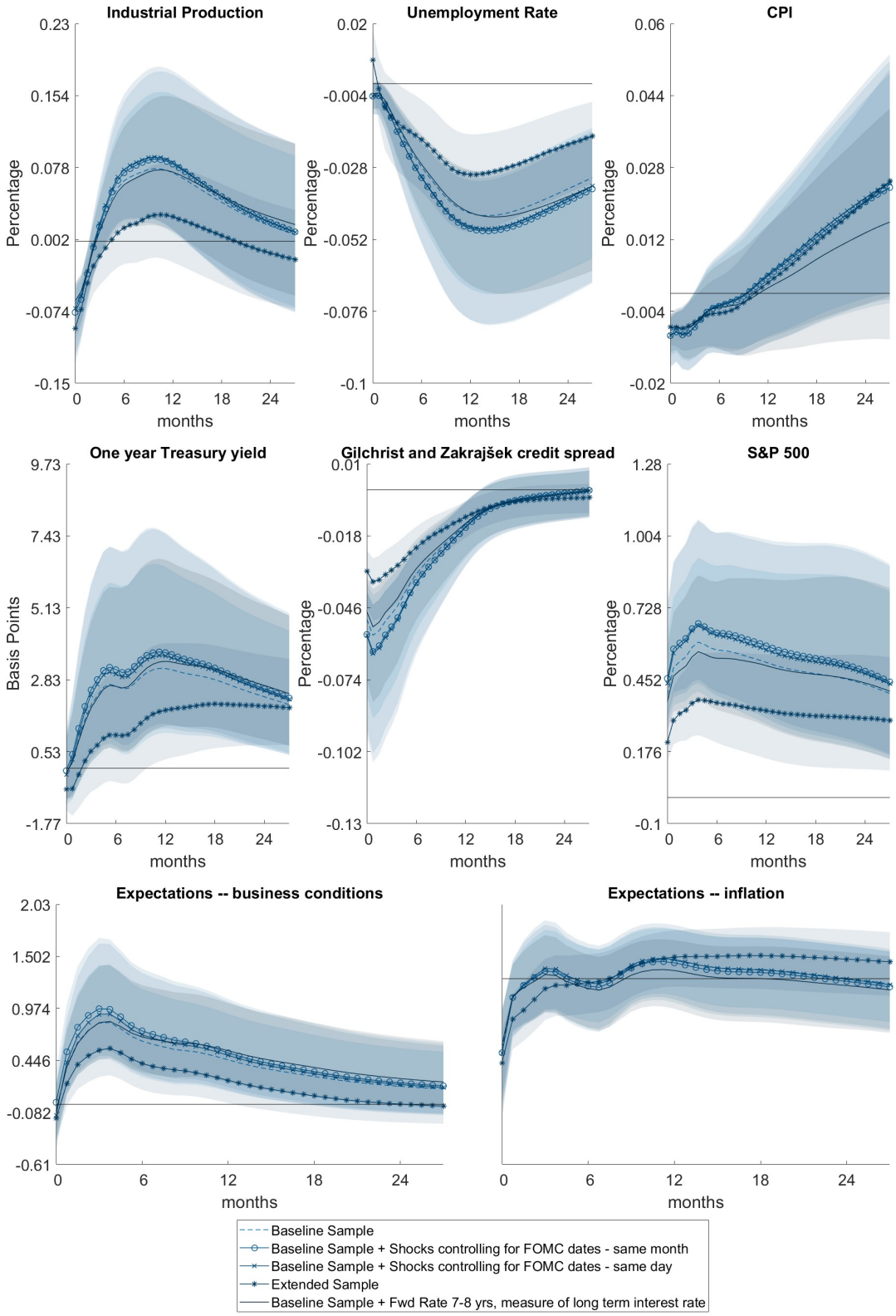


Figure 13: Robustness checks, QE shock: Impulse responses of the log of Industrial Production, log of the CPI, expectations about 12-months ahead business conditions and expectations about 12-month ahead inflation to a one-standard-deviation shock to one-year forward rate going from 9 to 10 years. Shaded areas denote 80% confidence bands.

shocks and which mimic LSAP shocks. Given its importance in the financial system and LSAP programs, I use the yield on the ten-year zero-coupon Treasury as a measurement of longer-term interest rate. On auction days, unforeseen variations in the demand for ten-year Treasuries around a tight thirty-minute window bracketing the closure generate a preferred habitat-like effect on the yield curve, which operates mainly via changes in the term premium.

To isolate a measure of long-term interest rate that is insensitive to shocks to the level and path of the federal funds rate, I decompose the 10-year yield into constituent forward rates and show that auction surprises have significant explanatory power in the movements of the forward rate going from 9 to years and monetary policy shocks have little or no impact.

I estimate a structural VAR model using the one-year forward rate going from nine to ten years as a measure of long-term interest rates and use auction-day surprises as an instrument proxying LSAP shocks. My results empirically confirm the validity of the credit spread channel in transmitting QE by demonstrating the link between balance sheet expansion, real activity, and borrowing costs in the economy, whereby a surprise decline in longer-term interest rates generates a sharp and persistent decline in credit spreads and a quantitatively significant improvement in different measures of economic activity. When the federal funds rate is unconstrained, I show that balance sheet normalization dampens economic activity and increases credit spreads modestly, but increases inflation. Both these findings are important since previous work examining the impact of LSAPs has been unable to credibly quantify the intended effects of balance-sheet policies on economic activity in the data. The results also establish the potency of balance sheet policies as an independent policy tool.

References

Adrian, T., R. K. Crump, and E. Moench (2013). Pricing the term structure with linear regressions. *Journal of Financial Economics 110(1)*, 110–138.

Altavilla, C., G. Carboni, and Y. Motto (2021). Asset purchase programs and financial markets: Lessons from the euro area. *International Journal of Central Banking 17(4)*, 1–48.

Baker, L., L. McPhail, and B. Tuckman (2020). The liquidity hierarchy in the us treasury cash and futures market. *The Journal of Fixed Income Summer*, 90–99.

Bauer, M. D. and E. T. Swanson (2023a). An alternative explanation for the "fed information effect". *American Economic Review*, 664–700.

Bauer, M. D. and E. T. Swanson (2023b). A reassessment of monetary policy surprises and high-frequency identification. *NBER Macroeconomics Annual 37*, 87–155.

Bernanke, B. S. (March 1, 2011). Semiannual monetary policy report to the congress before thecommittee on banking, housing, and urban affairs, u.s. senate. *Testimony: 2015-005*.

Gagnon, J., M. Raskin, J. Remache, and B. Sack (2011). Large-scale asset purchases by the federal reserve: Did they work? *FRBNY Economic Policy Review*, 41–59.

Gertler, M. and P. Karadi (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics 7(1)*, 44–76.

Giannone, D., M. Lenza, and G. E. Primiceri (2015). Prior selection for vector autoregressions. *The Review of Economics and Statistics*, 436–451.

Gilchrist, S. and E. Zakrajšek (2012). Credit spreads and business cycle fluctuations. *American Economic Review 102(4)*, 1692–1720.

Gurkaynak, R. S., B. Sack, and E. T. Swanson (2005). Do actions speak louder than words? the response of asset prices to monetary policy actions and statements. *International Journal of Central Banking May*, 55–93.

Gurkaynak, R. S., B. Sack, and J. H. Wright (2007). The u.s. treasury yield curve: 1961 to the present. *Journal of Monetary Economics 54(8)*, 2291–2304.

Jarociński, M. and P. Karadi (2020). Deconstructing monetary policy surprises — the role of information shocks. *American Economic Journal: Macroeconomics 12(2)*, 1–43.

Joyce, M. A. S., A. Lasaosa, I. Stevens, and M. Tong (2011). The financial market impact of quantitative easing in the united kingdom. *International Journal of Central Banking September*, 113–161.

Krishnamurthy, A. and A. Vissing-Jorgensen (2011). The effects of quantitative easing on interest rates: Channels and implications for policy. *Brookings Papers on Economic Activity Fall*, 191–239.

Miranda-Agrippino, S. and G. Ricco (2021). The transmission of monetary policy shocks. *American Economic Journal: Macroeconomics 13(3)*, 1283–1330.

Miranda-Agrippino, S. and G. Ricco (2023). Identification with external instruments in structural vars. *Journal of Monetary Economics*, 1–19.

Montiel Olea, J. L., J. Stock, and M. Watson (2021). Inference in structural vector autoregressions identified with an external instrument. *Journal of Econometrics 225*, 74–87.

Nakamura, E. and J. Steinsson (2018). High frequency identification of monetary non-neutrality: The information effect. *The Quarterly Journal of Economics*, 1283–1330.

Ramey, V. A. (2016). Macroeconomic shocks and their propagation. *Handbook of Macroeconomics 13(3)*, 1283–1330.

Ray, W., M. Droste, and Y. Gorodnichenko (2024). Unbundling quantitative easing: Taking a cue from treasury auctions. *Journal of Political Economy 32(9)*, 3115–3172.

Swanson, E. T. (2021). Measuring the effects of federal reserve forward guidance and asset purchases on financial markets. *Journal of Monetary Economics 118*, 323–53.

Swanson, E. T. (2024). The macroeconomic effects of the federal reserve's conventional and unconventional monetary policies. *IMF Economic Review*, 1152–1184.

Vayanos, D. and J.-L. Vila (2021). A preffered-habitat model of the term structure of interest rates. *Econometrica 89(1)*, 77–112.

Appendix

A Deriving forward rates

Following the notation in Gurkaynak, Sack, and Wright (2007), if $d_t(n)$ is the discount function, then the continuously compounded yield, $y_t(n)$ on an n-period zero-coupon bond is given by

$$y_t(n) = -ln(d_t(n))/n \tag{15}$$

and the yield on a n-by-m forward rate is given by

$$f_t(n,m) = -\frac{1}{m}\ln\frac{d_t(n+m)}{d_t(n)} = \frac{1}{m}[(n+m)y_t(n+m) - ny_t(n)] \tag{16}$$

Taking the limit of equation (16) as $m \to 0$, gives us the instantaneous forward rate, $f_t(n,0)$, n years ahead, which represents the instantaneous return for a future date (n years hence) which an investor demands today with

$$f_t(n,0) = y_t(n) + ny_t'(n). \tag{17}$$

Using equation (17), an investment today can therefore expressed as sum of forward rate agreements over the the horizon of the investment, with the yield equaling the average of the sequence of those forward rates.

$$y_t(n) = \frac{1}{n}\int_o^n f_t(x,0)dx \tag{18}$$

In discrete time, the n-period zero coupon yield on a security can be expressed as an average of one-year continuously compounded forward rates such that

$$y_t(n) = \frac{1}{n}\sum_{i=1}^{n} f_t(i,1) \tag{19}$$

Therefore for a zero-coupon security maturing in 10 years,

$$y_t(10) = \frac{1}{10}\sum_{i=1}^{10} f_t(i,1) \tag{20}$$

where $f_t(i,1)\ \forall i \in [0,9]$ is the one-year continuously compounded (i)-by-1 forward rate. Using equation (20), forward rates can be calculated as

$$f_t(i,1) = (i+1)y_t(i+1) - (i)y_t(i)\ \forall i \in [0,9] \tag{21}$$