Time series properties of US reference rates 2016-2023

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1 Abstract

How monetary policy impacts volatility of rates in the market for repurchase agreements also reveals the Federal Reserve preference for volatility as it manages the Federal Funds rate (FFR) within the target rate range specified by the FOMC. In the current ample reserves regime, the Fed's open market operations adjust reserves through repurchase transactions in the tri-party market to offset volatility in the Federal Funds rate. The Fed's changes in the FFR, the target rate, and the administered rates, the interest on reserves (IORB) and the overnight reverse repurchase rate (ONRRP) also impact money market rates in these key funding markets.

This paper describes the dynamics of these rates and proposes a model of volatility joint with monetary policy to understand how different monetary policy regimes may reveal the Fed's preferences for offsetting volatility in managing the FFR within the FOMC target range.

2 Introduction

I examine how monetary policy impacts volatility of rates in the market for repurchase agreements may reveal the Federal Reserve Bank (Fed) preference for volatility as it manages the Federal Funds rate (FFR) with the target range specified by the FOMC. The Fed's open market operations adjust reserves through repurchase transactions to offset shocks to the Federal Funds rate.

The Federal Funds rate is the Fed's policy rate, the rate banks exchange funds in the interbank market. The administered rates for setting policy, interest on reserves (IORB) and the overnight reverse repo rate are important tools for managing the FFR.

The excess liquidity created by quantitative easing after the Great Financial Crisis (GFC) challenged the Fed's ability to manage short term rates. Events like the spikes in repo and the FFR in 2019, the March 2020 dash for cash show how the adjustment of reserves through repurchase markets and the arbitrage opportunities between repo and the price of reserves affect credit and the economy. By increasing reserves through purchases of securities, the Fed can lower the FFR or raise the FFR by selling securities in reverse repurchase transactions. In a repurchase transaction, the Desk buys securities from a counterparty and agrees to resell them later. This increases reserves and lowers the FFR. in a reverse repo transaction, the Desk sells securities to a counterparty subject to an agreement to repurchase the securities at a later date. Reverse repo transactions temporarily reduce the supply of reserve balances in the banking system and raise the FFR.

The daily $4 trillion repurchase market market provides liquidity to primary dealers, hedge funds, money market funds, government-sponsored enterprise (GSEs), banks, and private investors. Bank reserves and deposits are regularly swapped for Treasuries and other securities, which are then swapped for repurchase agreements (repos) used to fund loans, obtain leverage, and many other functions.

The repurchase funding market rates are: - Triparty General Collateral Rate (TGCR) — the major dealer funding market - GCF — the interdealer repo market - Bilateral General Collateral Rate (BGCR) — the dealer-to-customer repo market - The Secured Overnight Financing Rate (SOFR) - the Fed's broadest measure of repo rates for borrowing collateralized by US Treasury securities.

Repurchase and reverse repurchase funding markets have become a major source of funding for primary dealers, hedge funds, government-sponsored enterprise (GSEs), money market funds (MMFS) and other participants. The tri-party general collaterial market is repo's primary funding market for cash lenders or borrowers. Primary dealers appointed by the Fed are required to intermediate new US Treasury issues. Primary dealers borrow at cheaper rates from lenders, asset managers and the Fed in the tri party , then lend at a spread in other repo markets. Loans are secured by collateral. They lend at the higher broad General Collateral Rate (BGCR) to leveraged investors such as hedge funds.The Fed conducts OMO in the tri party market, both borrowing and lending. The Secured Overnight Financing Rate (SOFR), Fed's broadest measure of repo rates, expresses the average cost of borrowing overnight.

To manage the federal funds rate within its target range, the Federal Reserve responds to volatility in the federal funds rate by adjusting reserves through repo and reverse repo operations in the tri-party market. Federal Reserve purchases or sales of assets from banks change the size of the Federal Reserve balance sheet. The Federal Reserve manages the FFR with temporary borrowing, repurchase agreements and lending, reverse repurchase agreements. The Fed is the only major participant to engage in both tri-party repo borrowing and lending. A repurchase transaction or repo is a loan secured by collateral subject to an agreement to resell the securities at a later date. The borrower issues a cash equivalent liability to the lender. In a reverse repo an entity lends cash against secured collateral. The transaction temporarily increases the supply of reserve balances in the banking system and lowers the FFR. In a reverse repo transaction, the Desk sells securities to a counterparty subject to an agreement to repurchase the securities at a later date. Reverse repo transactions temporarily reduce the supply of reserve balances in the banking system and raise the FFR.

The Federal reserve has established facilities for dealers and investors, the Standard Repurchase Facility (SRF) to fund dealers, and the Overnight Reverse Repurchase Facility (O/N RRP) for lenders to invest excess liquidity. Identifying the behavior and relationships among these reference rates, policy and money market rates, is important to understanding the monetary system.

This paper describes the dynamics of these rates and proposes a model of volatility joint with monetary policy. How that volatility may vary under different monetary policy regimes may reveal the Fed's preferences for offsetting volatility in managing the FFR within range specified by the FOMC.

Section 1 reviews monetary policy over the seven year period, 2016-2023 and identifies FOMC rate changes, monetary regimes, and events in order to define monetary shocks. Section 2 reviews the time series properties of daily policy and money market rates and transactions from 3/4/2016-12/14/2023. describes rate behavior during different policy episodes, presents The FFR and the FOMC target range, and identifies important arbitrage relationships. Section 3 surveys potential shocks to the Fed Funds rates available in existing databases. Section 4 discusses methodology for modelling volatility of the EFFR. Section 5 presents results. Section 6 concludes. (Sections 5-6 are in progress).

Hamilton (1996) was the first to estimate the conditional mean and variance of the daily Federal Funds rate in an adaption of Nelson's (1991) EGARCH model. He conlcuded open-market purchases rather than interday arbitrage ofset fluctuations in the FFR. Adding reserves through an overnight repurchase agreement lowers the federal funds rate by inducing movement along a schedule that represents lending banks' liquidity benefit from holding excess reserves. Important day effects, the last day of the quarter or the last day of the year are responsible for large outliers of the FFR, the extreme volatility.

Piazzesi (2005) exploits that both Federal Reserve and financial markets interpret each others actions through bond yields. A continuous-time linear-quadratic jump-diffusion model of the joint distribution of high-frequency bond yields and the FOMC FFR target rate provides information about the exact timing of FOMC meetings, improves bond pricing and the ability to identify monetary policy shocks. Yield-based information that may underlie the FOMC's policy decisions describes Fed policy better than Taylor rules. The Fed's estimated policy rule reacts to information in the yield curve, especially yields with two year maturities, implying the Fed responds to some medium-run forecast of the economy. The short informational lag before Fed's policy decision, information available right before the FOMC meeting start provides a recursive identification scheme that turns the target forecast from right before the Federal Open Market Committee (FOMC) meeting into a high-frequency policy rule and the associated forecast errors into policy shocks. Estimates reveals increased volatility of interest rates at all maturities in both FOMC meeting days and releases of key macroeconomic data.Policy inertia is observed in the Fed incremental implementation of changes in the FFR.

(Andersen, Benzoni,Lund, 2004) model the U.S. short-term interest rate 3 month Tbill with a three-factor jump-diffusion model, a time-varying mean reversion factor, a stochastic volatility factor, and a jump process. The U.S. short-term interest rate is characterized by complex conditional heteroskedasticity, fat-tailed innovations, and pronounced autocorrelation patterns. Stochastic volatility is critical for a good fit. Benzoni et al identify mean reversion of the short rate around a central tendency. The stochastic mean allows a relatively fast mean-reversion of the short rate around a highly persistent time-varying central tendency process. Jumps are integral to the quality of fit and relieve the stochastic volatility factor from accommodating extreme outlier behavior.

The mean drift may be indicative of slowly evolving inflationary expectations, time-variation in the required real interest rate, or both.

Bertolini, Bertola, Prati (2000), Anderson, Benzoni, Lund (2004) observe volatility in interbank rates from Fed interventions: * declines in high rate regimes
* rises end of quarter, end of year
* falls before holidays, rises day after
* many rate changes are half percent or more (annualized)
* outliers
* Verify Hamilton's observations that volatility is persistentand pronounced at end of quarter, end of year, before and after holidays, large rate changes.

Bertolini, Bertola, Prati (2000) predict patterns of the Federal Funds rate's volatility and its response to changes in FOMC target rates and Fed interventions to manage the FFR withing the target range.They model banks' liquidity management joint with the Fed's intervention withing the institutional features of the Federal Funds market.Their interest is the high frequency in volatility of the FFR survive the Fed's attempt to manage the rate. Their model of FFR volatility seeks to isolate Fed preferences for offsetting volatility in the FFR market in an EGARCH model of the log volatility of the FFR. Overnight wholesale money market rates both track the FFR and quickly revert to changes in the unsecured federal funds rate (FFR) or administered rates.

Gara Afonso, Kyungmin Kim, Antoine Martin, Ed Nosal, Simon Potter, and Sam Schulhofer-Wohl derive a function of reserve demand that describes the price at which banks are willing to trade reserves as a function of the total amount of reserves in the banking system. The function measures banks' demand for liquidity as a function of aggregate reserves and the FFR under the Fed's policy of ample supply of reserves (2020). The FFR is price at which banks are willing to borrow and lend reserve balances.The Banks' reserve demand sensitivity to shocks to reserves is greater when reserves are scarce.

Policy changes shift the curve up and down by moving its lower bound. Increases (decreases) in the (FFR-IORB) IORB rate shift the demand curve down (up by changing the banks' opportunity cost of lending in the federal funds market. Low frequency horizontal shifts in the demand function reflect sensitivity of rates to shocks to reserves

The Romer and Romer (2023) narrative approach to macroeconomic shocks identify as significant contractionary and expansionary changes in monetary policy not taken in response to current or prospective developments in real activity. However, this approach would exclude shocks such as policy changes such as QE, LSAP, and forward guidance or events such the spike in repo rates in 2019 or the March 2020 dash for cash.

Jarocinski (2002) Another literature identifies monetary policy shocks from changes of financial asset prices in a narrow time window around Federal Open Market Committee (FOMC) announcements. Prior to the announcement, asset prices reflect the consensus view on the state of the economy and the Fed's expected response to it. Afterwards, asset prices incorporate also any unexpected news conveyed in the announcement. These news could be about the current fed funds rate or its future path, asset purchases, the Fed's view on the state of the economy, etc. They represent different structural shocks that may affect the economy differently.

Estimating the Fed's unconventional policy shocks, Jarocinski (2022) estimates structural shocks that underlie the reactions of financial markets to FOMC announcements. While the nature of the shocks is not specified ex ante, ex post the estimated shocks can be naturally labeled as the current fed funds rate policy, an “Odyssean” forward guidance (a commitment to a future course of policy rates), a large scale asset purchase and a “Delphic” forward guidance (a statement about the future course of policy rates understood as a forecast of the appropriate stance of the policy rather than a commitment (Campbell et al., 2012).

3 Time series properties of overnight policy, money market rates, transactions, and reserves held at the Federal Reserve

Daily weighted average median rates reference rates, both policy and money market rates from the NY Federal Reserve download program are the effective (transaction weighted) Federal funds rate (EFFR) that tracks transactions in the Federal funds market, the secured overnight funding rate (SOFR) that captures transactions in overnight wholesale funding markets, and the money market rates - the Tri-Party General Collateral Rate (TGCR) and the broad general collateral rate (BGCR).

Overnight money market rates in funding markets share several features. They closely closely track and cluster around the Fed policy rate, the EFFR. They respond quickly to changes in the EFFR or the administered rates IORB and ON RRP (Figure 1. Their medians change over time, their small interquartile range (IQR) indicates that they cluster tightly around their medians. They contain extreme values or outliers, characteristic of fat tailed distributions. Rates are heteroskedastic - volatility as measured by percent change in in the sum of squared median returns varies over time.

3.1 Characteristics of the sample 2016-2023

The average volume weighted median rate data are a better measure of central tendency since daily rates have skewed distributions with outliers. Less influenced by extreme values, the Interquartile range (IQR), the 75th minus the 25 percentile of the data, contains 50 percent of the data indicating how tightly the data cluster around the median. The range, the 99th minus the one percentile, some two percent of rates, show the magnitude of the outlier rates (Table (@ref(tab:Rate characteristics 2016-2023)).

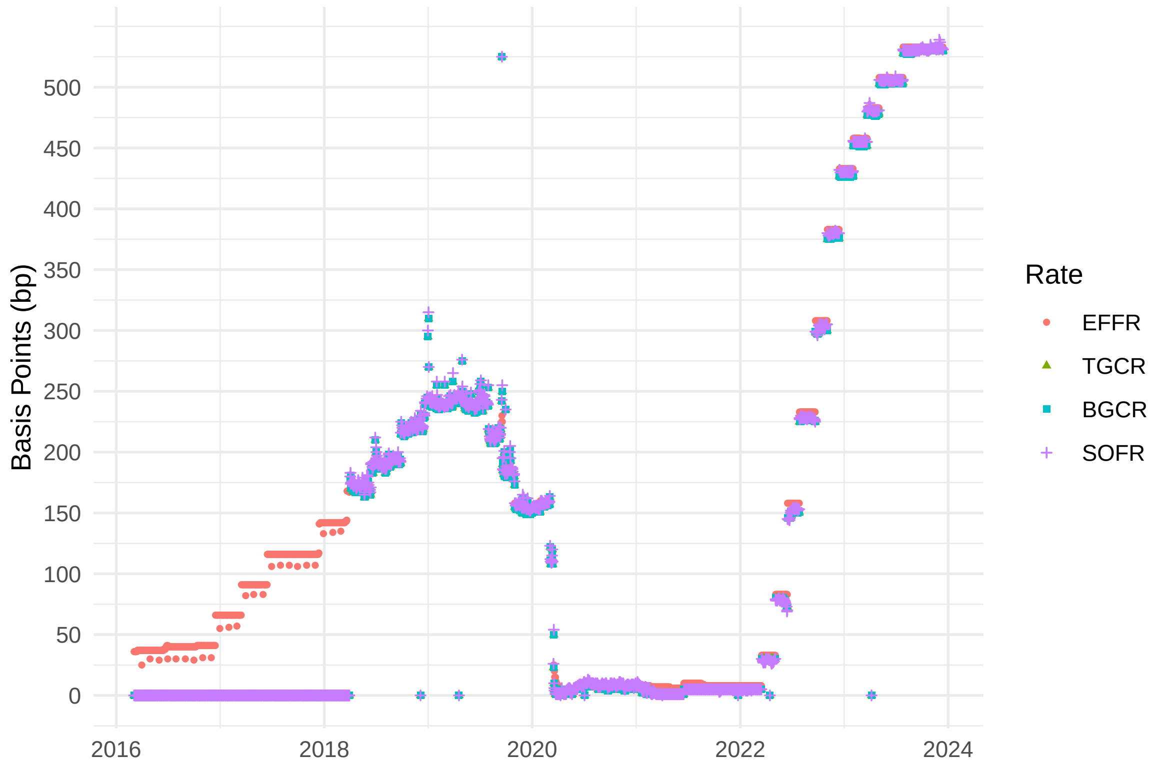

Figure 1: Sample reference rates 3/4/2016-12/14/2023

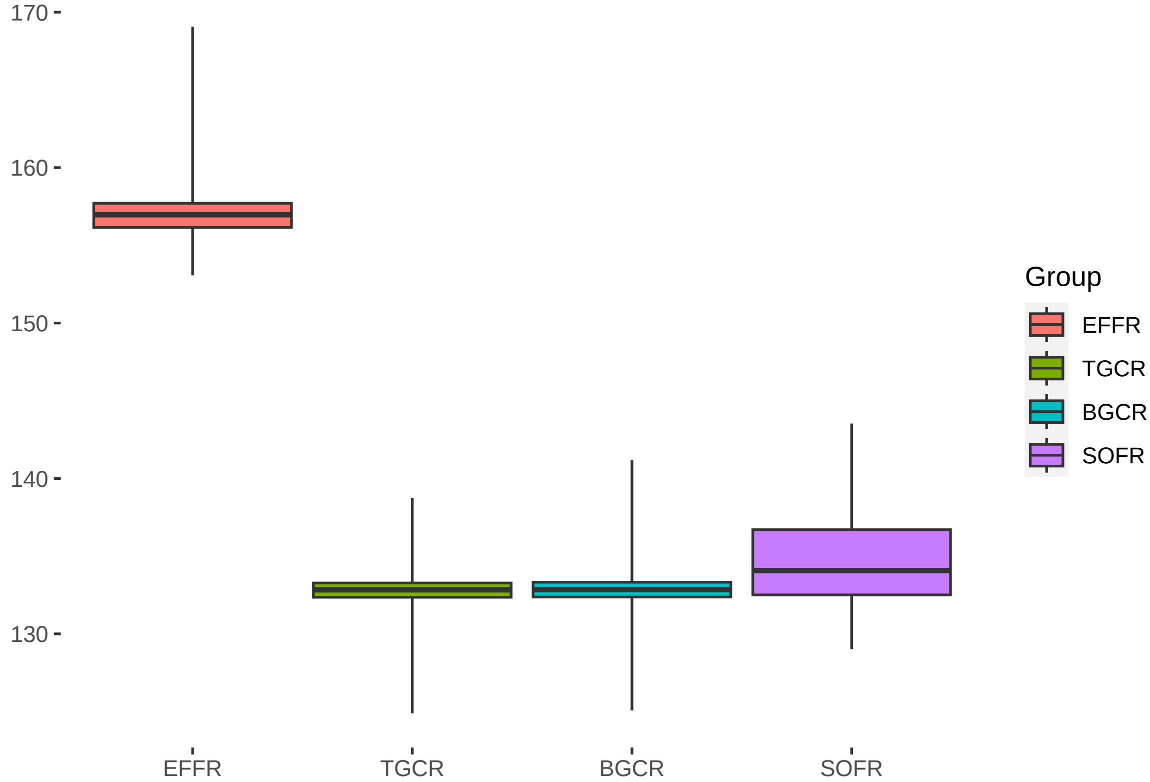

Figure 2: EFFR IQR and range of the sample 3/4/2016-12/14/2023

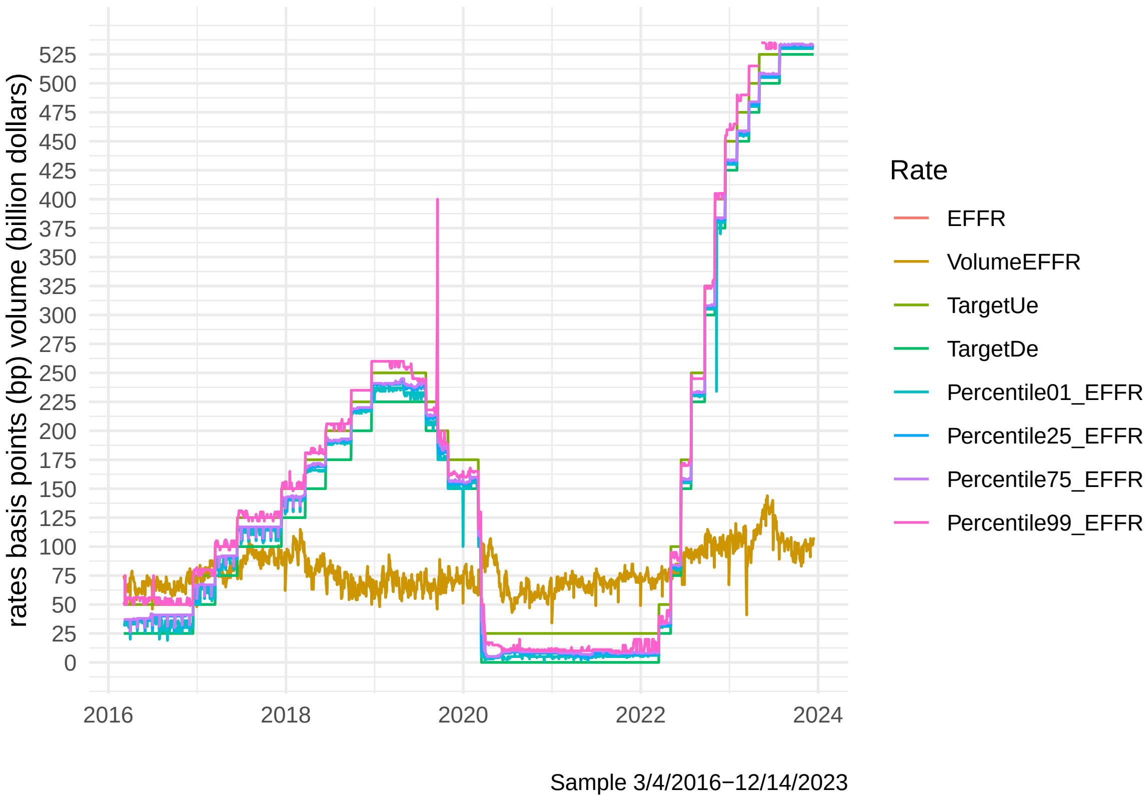

Figure 3: EFFR percentiles of the sample 3/4/2016-12/14/2023

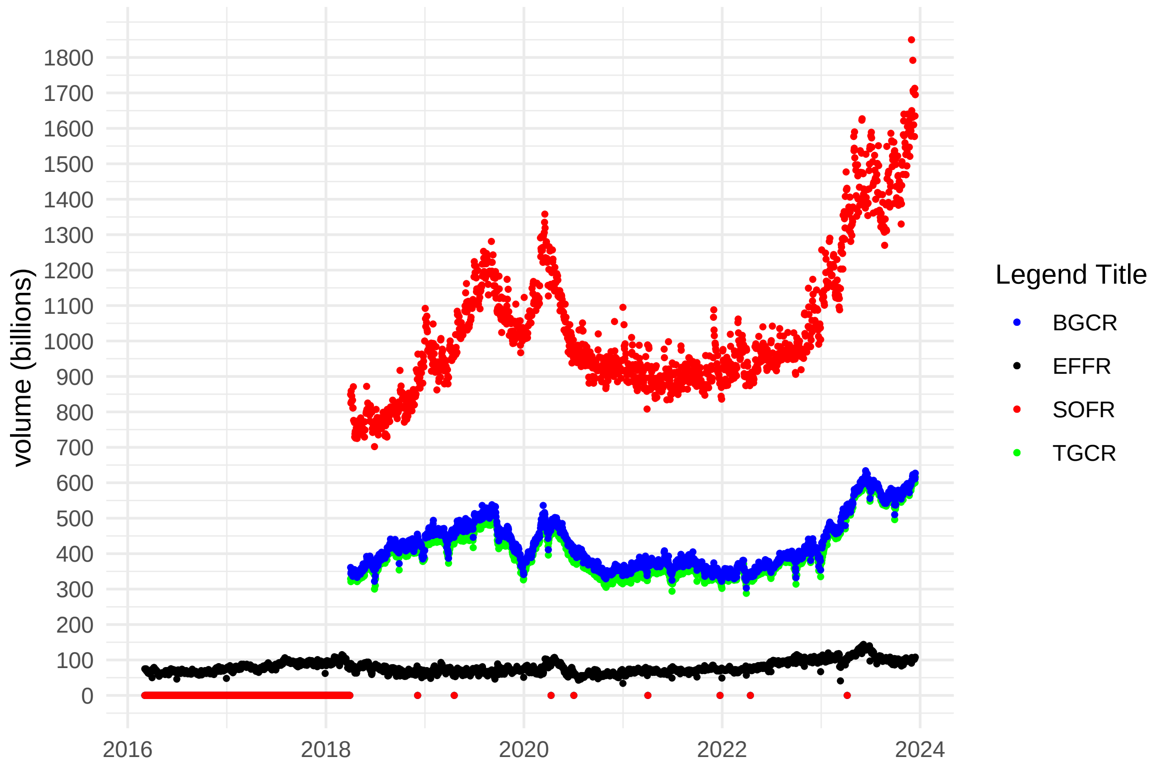

Figure 4: Sample volumes of overnight rates 3/4/2016-12/14/2023

Funding rates track the FFR Median funding rates closely track the the policy rate, the effective Federal funds rate (EFFR) (Table @ref(tab:Sample statistics 2016-2023)). Similar average median rates illustrate the tendency of money market rates and SOFR to cluster around the EFFR. The average median EFFR over the full sample is 157 basis point (bp), the money market rates about 132-134 bp - Tri-Party General Collateral Rate (TGCR), the Broad General Collateral Rate (BGCR) 133 bp, the the Secured Overnight Financing Rate (SOFR), 134 bp. The percentiles of rates reflect the same clustering around the EFFR (Figure 3).

Variability: Small IQRs for all rates except SOFR, indicate rates cluster tightly around their median values .Fifty percent of EFFR daily rates fall within 157.71-156.15 bp, an IQR of 1.56 basis points, the TGCR and BGCR cluster even more tightly, under one bp (133), SOHR shows greater dispersion, 4.2 bp (Figure 2).

Outliers The EFFR and money market rates are skewed with fatter tails. The range of the EFFR and the money market rates, two percent of the data in the 99th minus the one percentile show sample TGCR, BGCR, and SOFR rates are some 14 to 16 basis points - 15.99 (EFFR), 13.86 (TGCR), 16.11 (BGCR), and 14.51 (SOFR) basis points. The larger the range, the higher the variability

Volatility The change in volatility over time, the percent change in median reference rates, indicates heteroskedasticity in rate data. From 2016 to 2020, the percent change in these daily rates, ranges plus of minus 0.5 percent from 2016 to November 2019 (Figure 5). From 2020 to 2022 during the pandemic until the Fed began its fight to contain inflation in 2023, the percent change in rates varies plus or minus 2 percent. Volatility falls steadily during the fight against inflation.

Volume The volume of SOFR transactions, $754 billion per day, dwarf trading in all other EFFR and money market rates. EFFR has a notably lower daily trade volume of $79 billion, TGCR and BGCR at around $300 billion each (TGCR 296.95, BGCR 311.23) (Figure 4).

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	EFFR	TGCR	BGCR	SOFR
Rate	156.97	132.83	132.85	134.08
Volume	78.91	296.95	311.23	754.37
Upper target	170.52			
Lower target	145.52			
Percentile_01	153.07	124.89	125.07	129.02
Percentile_25	156.15	132.36	132.37	132.51
Percentile_75	157.71	133.27	133.32	136.70
Percentile_99	169.06	138.75	141.19	143.53

Table 1: Rate characteristics 2016-2023

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	Category	Median	IQR	RANGE	VOLUME
1	EFFR	156.97	1.56	15.99	78.91
2	TGCR	132.83	0.92	13.86	296.95
3	BGCR	132.85	0.96	16.11	311.23
4	SOFR	134.08	4.20	14.51	754.37

Table 2: Sample 3/04/2016-12/14/2023

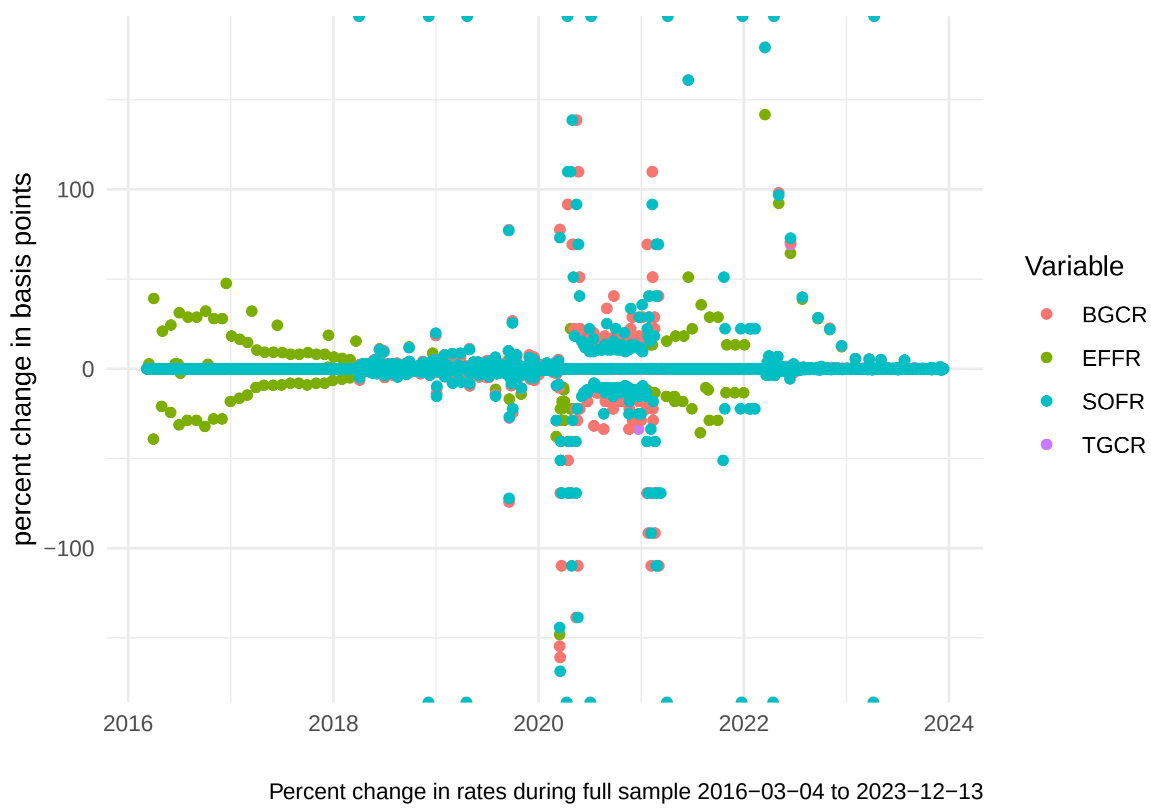


Figure 5: Volatility percent change daily rates 2016-2023

3.2 Behavior the Federal Funds rate and money market rates during different policy episodes

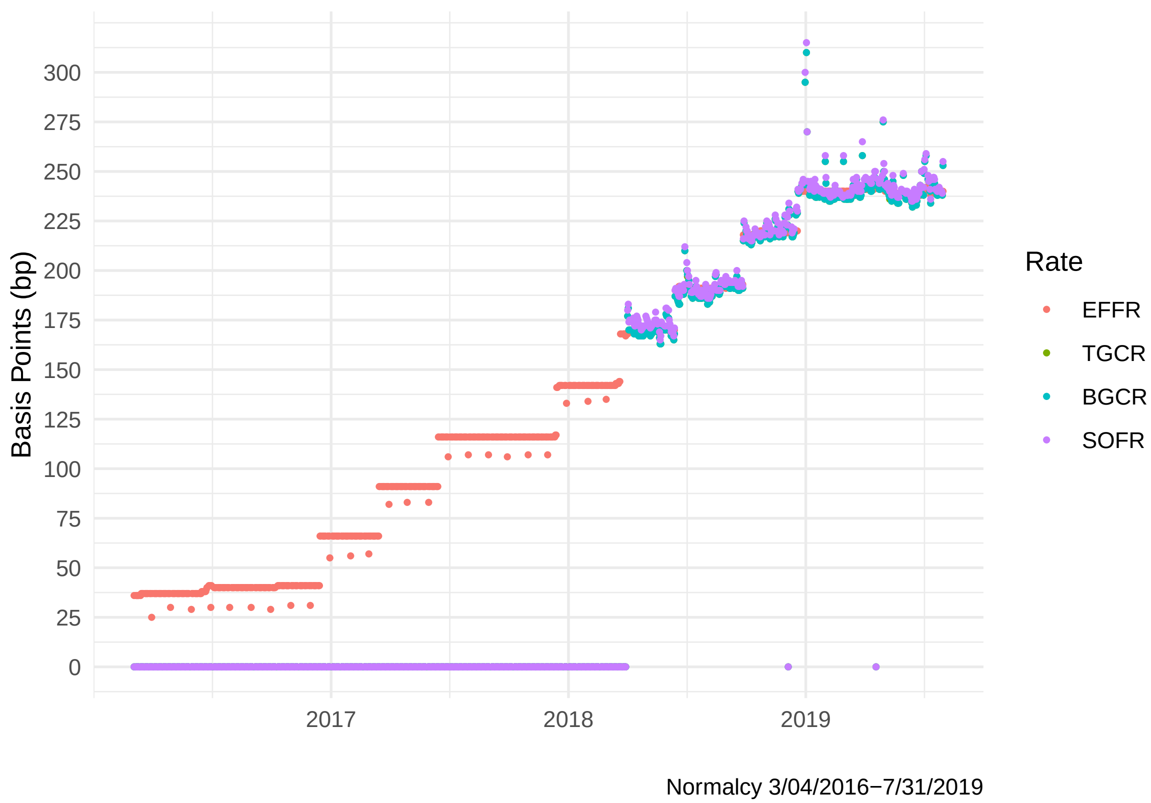
The vertical shifts in rates from 2016 to 2023 suggest changes in distribution of rates during policy episodes. Forbes (2024) summarizes these monetary policy episodes (https://www.forbes.com/advisor/

investing/fed-funds-rate-history/):

- Normalcy 3/4/2016 to 7/31/2019 (Figure **??**
- Mid cycle adjustment 8/1/2019 to 10/31/2019 (Figure **??**
- Covid 11/1/2019 to 3/16/2020 (Figure 6
- Zero lower bound 3/17/2020 to 3/16/2022 (Figure 7
- Taming inflation 03/17/2022 - 12/14/2023 (Figure **??**.

I have added the period of the zero lower bound. A rigorous approach to identifying change in regimes is offered by (Valeria Gargiulo, Christian Matthes, and Katerina Petrova,2024) and (Bianchi, Ludvigson, and Ma, 2024).

During the period of normalcy, there were a series of 25 basis point (bp) increase in the EFFR from 2016 to mid 2019 3). During the mid cycle adjustment there were plus or minus 25 bp changes in the EFFR from August to November 2019 4). During covid from November 2019 to mid March 2020, there were a series of 25 bp increases 5). There were no changes in the policy rate during the zero lower bound period in 2020-2021. From March 17, 2022 to December 14, 2023, the Fed raised the FFR in steady increments of 25, 50, and 75 bp 7).



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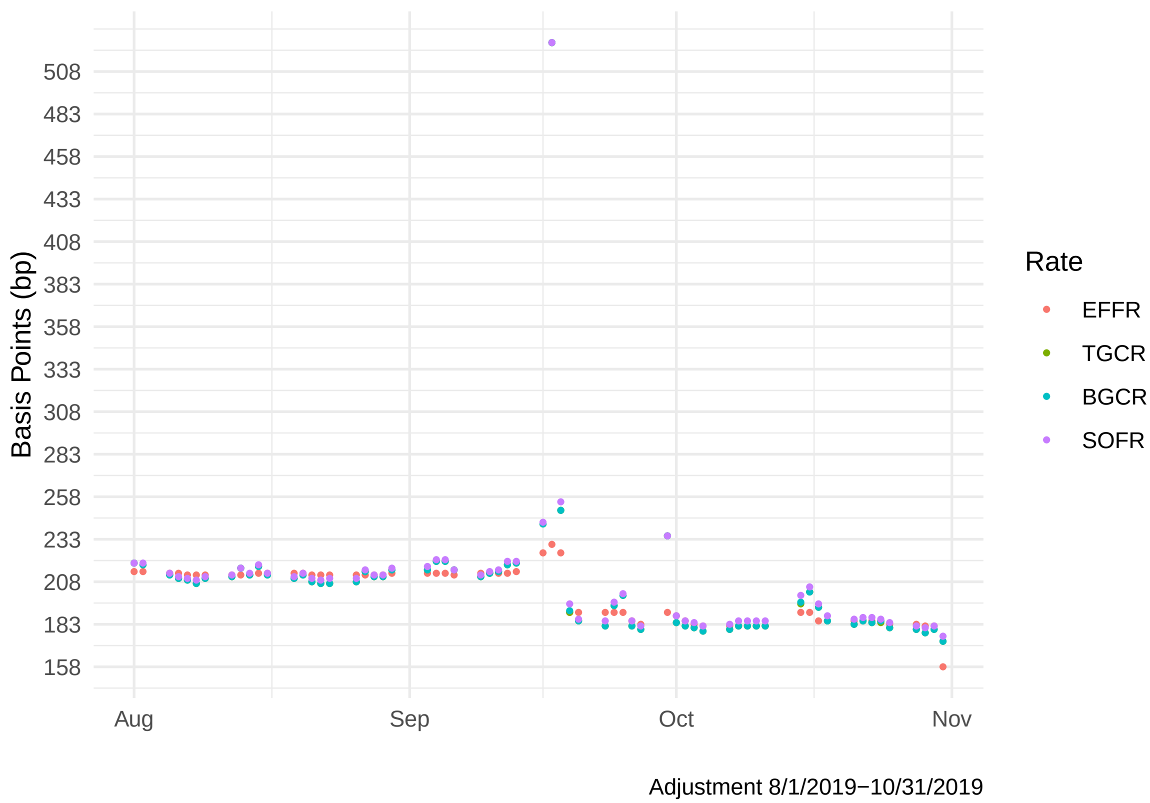
	Date	From	To	Basis.points	Discount.rate	Votes
1	14-Dec-16	0.50	0.75	25	0.01	10–0
2	15-Mar-17	0.75	1.00	25	0.01	9–1
3	14-Jun-17	1.00	1.25	25	0.02	8–1
4	13-Dec-17	1.25	1.50	25	0.02	7–2
5	21-Mar-18	1.50	1.75	25	0.02	8–0
6	13-Jun-18	1.75	2.00	25	0.02	8–0
7	26-Sep-18	2.00	2.25	25	0.03	9–0
8	19-Dec-18	2.20	2.50	25	0.03	10–0
9	31-Jul-19	2.00	2.25	-25	0.03	8–2

Table 3: FOMC rate changes Normalcy 3/4/2016 to 7/31/2019



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	Date	From	To	Basis.points	Discount.rate	Votes
10	18-Sep-19	1.75	2.00	25	0.03	7–3
11	30-Oct-19	1.50	1.75	-25	0.03	8–2

Table 4: Mid cycle adjustment 8/1/2019 to 10/31/2019

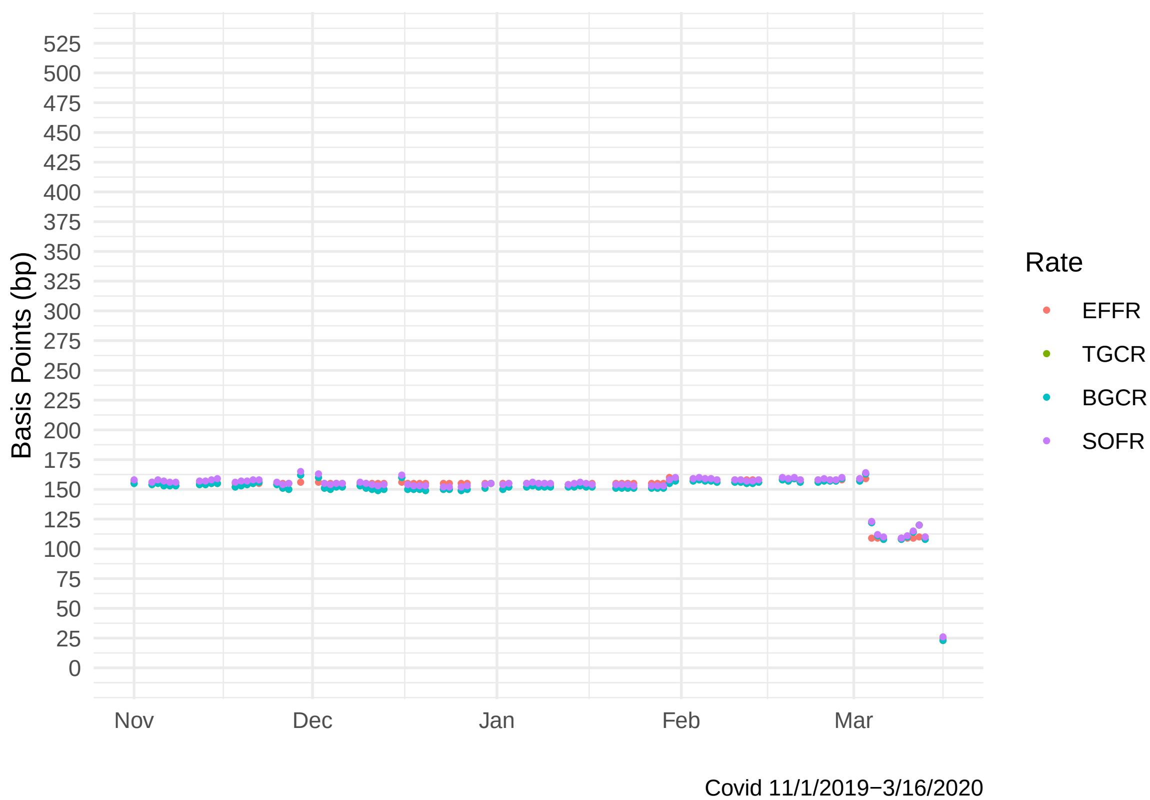

Figure 6: Rates during covid 11/1/2019-3/16/2020

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	Date	From	To	Basis.points	Discount.rate	Votes
12	3-Mar-20	1.00	1.25	25	0.03	10–0
13	15-Mar-20	0.00	0.25	25	0.00	9–1

Table 5: Covid 11/1/2019 to 3/16/2020

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	Date	From	To	Basis.points	Discount.rate	Votes
14	19-Mar-20	0.00	0.25	25	0.00	
15	23-Mar-20	0.00	0.25	25	0.00	
16	31-Mar-20	0.00	0.25	25	0.00	
17	29-Apr-20	0.00	0.25	25	0.00	
18	10-Jun-20	0.00	0.25	25	0.00	
19	29-Jul-20	0.00	0.25	25	0.00	
20	27-Aug-20	0.00	0.25	25	0.00	unanimous
21	16-Sep-20	0.00	0.25	25	0.00	
22	5-Nov-20	0.00	0.25	25	0.00	

Table 6: Zero lower bound 3/17/2020 to 3/16/2022

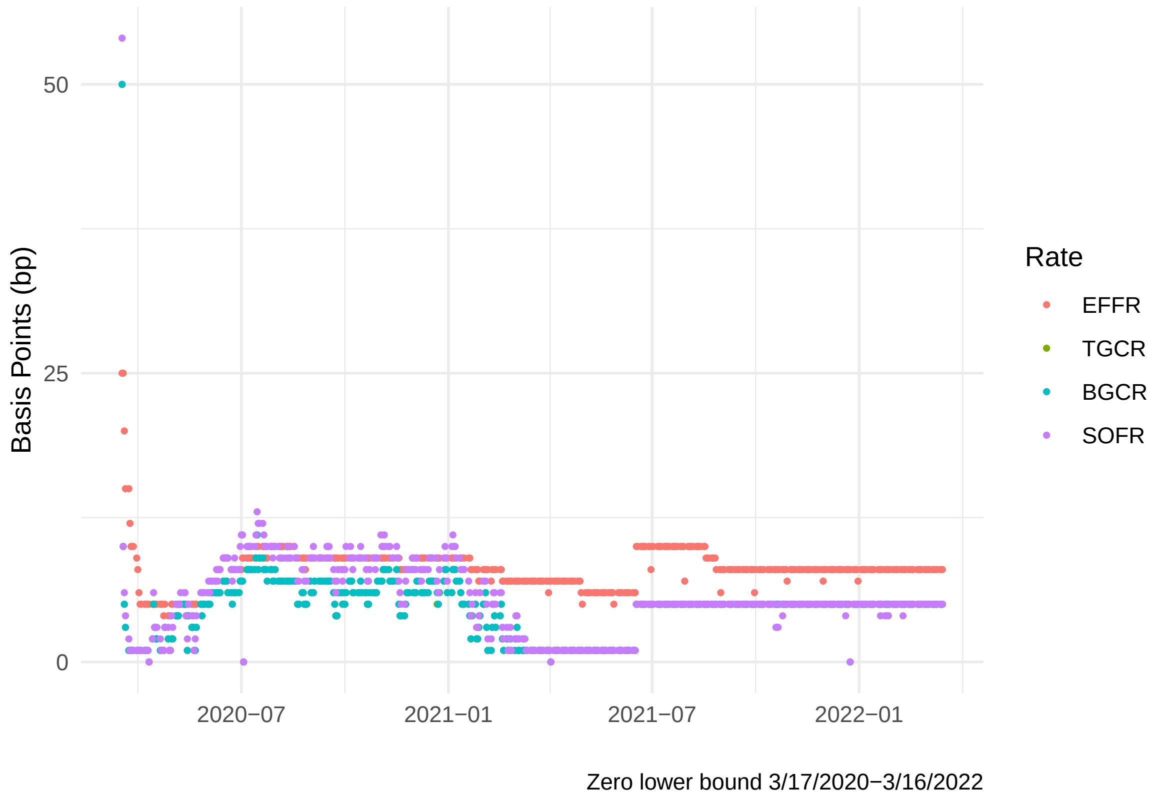
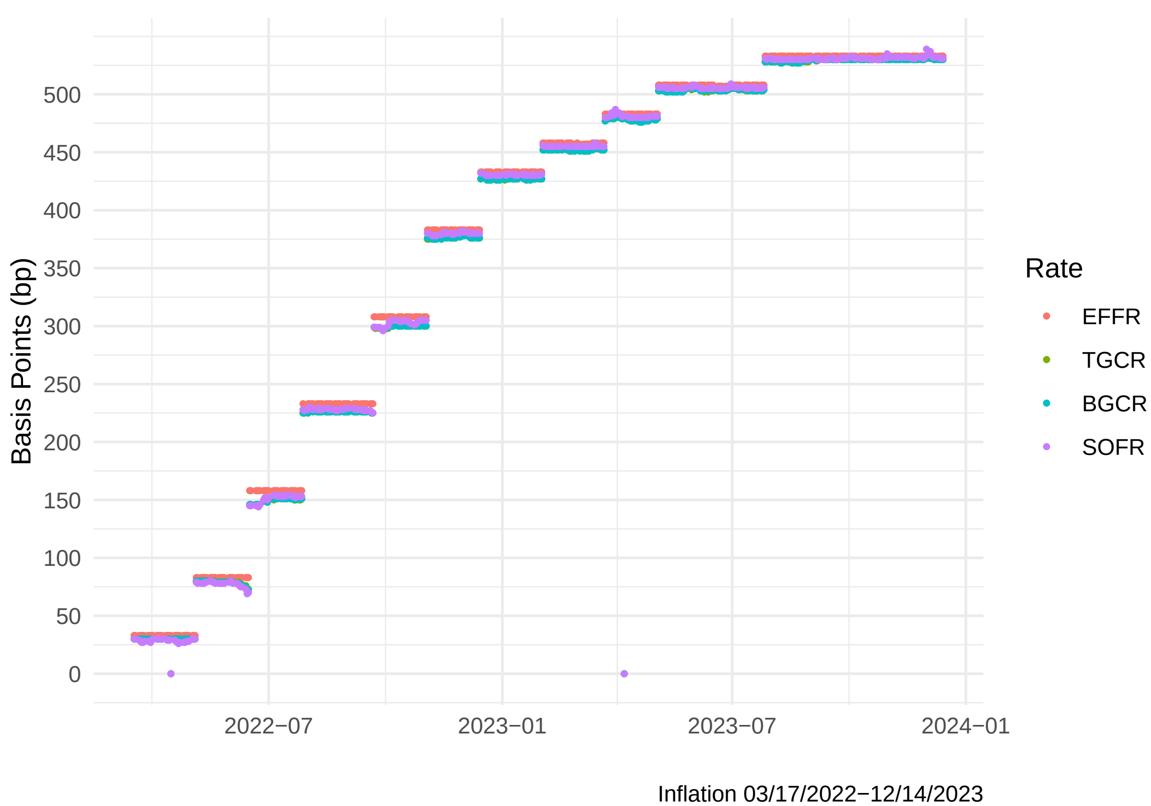


Figure 7: Rates during zero lower bound 3/17/2020-3/16/2022



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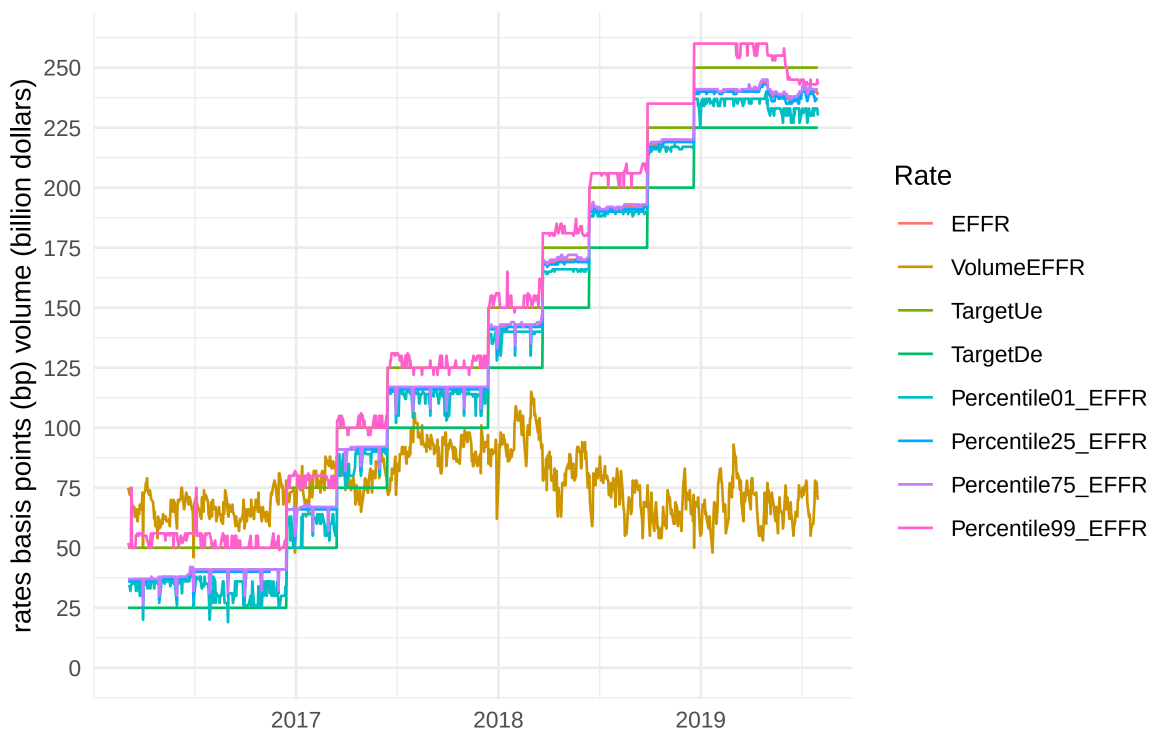
	Date	From	To	Basis.points	Discount.rate	Votes
24	4-May-22	0.75	1.00	25	0.01	9–0
25	15-Jun-22	1.50	1.75	25	0.02	8–1
26	27-Jul-22	2.25	2.50	25	0.02	12–0
27	21-Sep-22	3.00	3.25	25	0.03	12–0
28	2-Nov-22	3.75	4.00	25	0.04	12–0
29	14-Dec-22	4.25	4.50	25	0.04	12–0
30	1-Feb-23	4.50	4.75	25	0.05	12–0
31	22-Mar-23	4.75	5.00	25	0.05	11–0
32	3-May-23	5.00	5.25	25	0.05	11–0
33	14-Jun-23	5.00	5.25	0	0.05	11–0
34	26-Jul-23	5.25	5.50	25	0.06	11–0
35	20-Sep-23	5.25	5.50	0	0.06	12–0
36	1-Nov-23	5.25	5.50	0	0.06	12–0
37	13-Dec-23	5.25	5.50	0	0.06	12–0

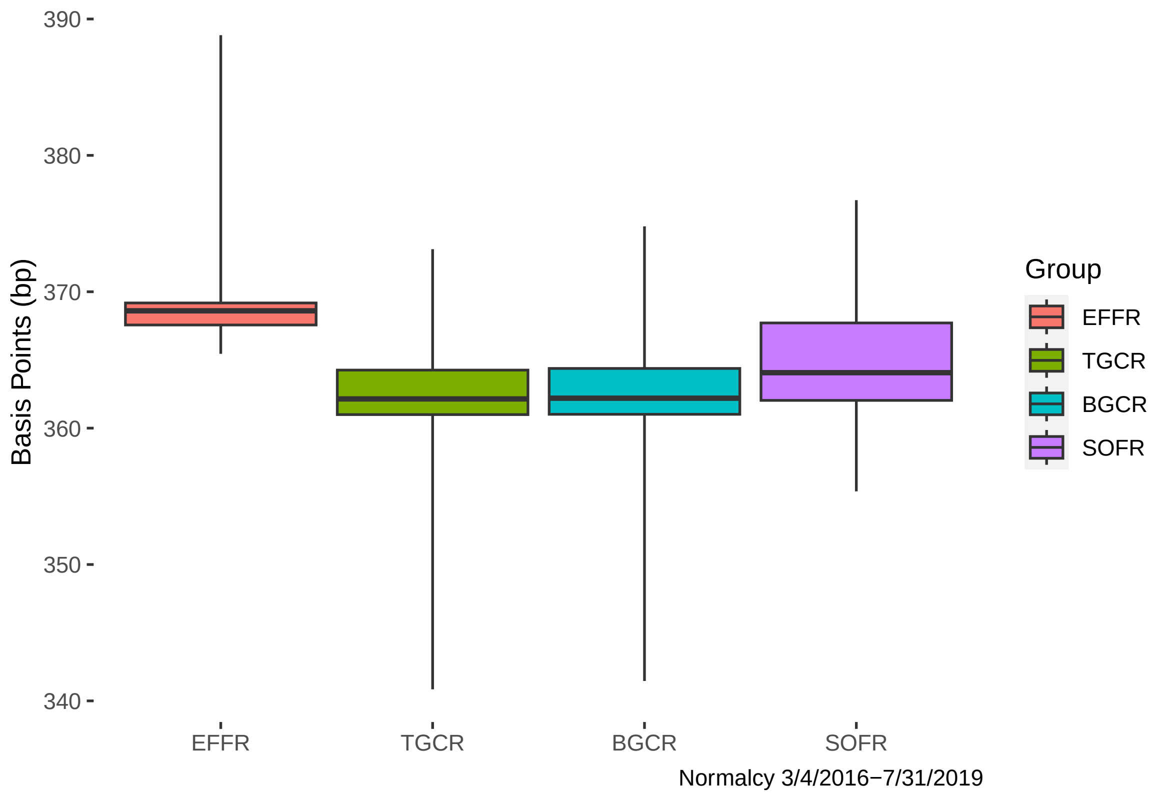
Table 7: Taming inflation 03/17/2022 to 12/14/2023

3.3 The FFR and the FOMC target range



Normalcy 3/4/2016−7/31/2019

The normalcy period The EFFR, median and IQR values are within the FOMC target ranges (the green step function for the lower and upper target rates, TargetDe, and TargetUe)(Figure **??**). The median EFFR is 133.8 bp, the IQR 1.22 (Table 9). The The 99th percentile of the EFFR is outside the FOMC target range for most of the period. The average 99th percentile of the EFFR is 147 bp (Table 8).



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	EFFR	TGCR	BGCR	SOFR
Rate	133.79	83.83	83.84	84.78
Volume	75.86	158.53	166.42	350.22
Upper target	143.09			
Lower target	118.09			
Percentile_01	129.38	79.88	79.97	81.44
Percentile_25	133.33	83.44	83.45	83.55
Percentile_75	134.55	83.66	83.68	86.85
Percentile_99	147.02	85.50	88.44	89.97

Table 8: Normalcy 3/04/2016-7/31/2019

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	Category	Median	IQR	RANGE	VOLUME
1	EFFR	133.79	1.22	17.65	75.86
2	TGCR	83.83	0.22	5.62	158.53
3	BGCR	83.84	0.23	8.48	166.42
4	SOFR	84.78	3.30	8.53	350.22

Table 9: Normalcy 3/04/2016-7/31/2019

The adjustment period The 99th percentile represents the outlier from the spike in repo rates September 2019 is the only time the FFR was not within the FOMC target range (Figure **??**). [CHECK ON DROP All quantiles? beg pandemic, check date] The EFFR, median and IQR values are within the FOMC target ranges (the green step function for the lower and upper target rates, TargetDe, and TargetUe) . The median EFFR is 183.59 bp, the IQR 12.84 (Table 11). The The 99th percentile of the EFFR is outside the FOMC target range for most of the period. The average 99th percentile of the EFFR is 209.8 bp (Table 10).

The rate statistics the adjustment period are shown in (Table 11). .–>

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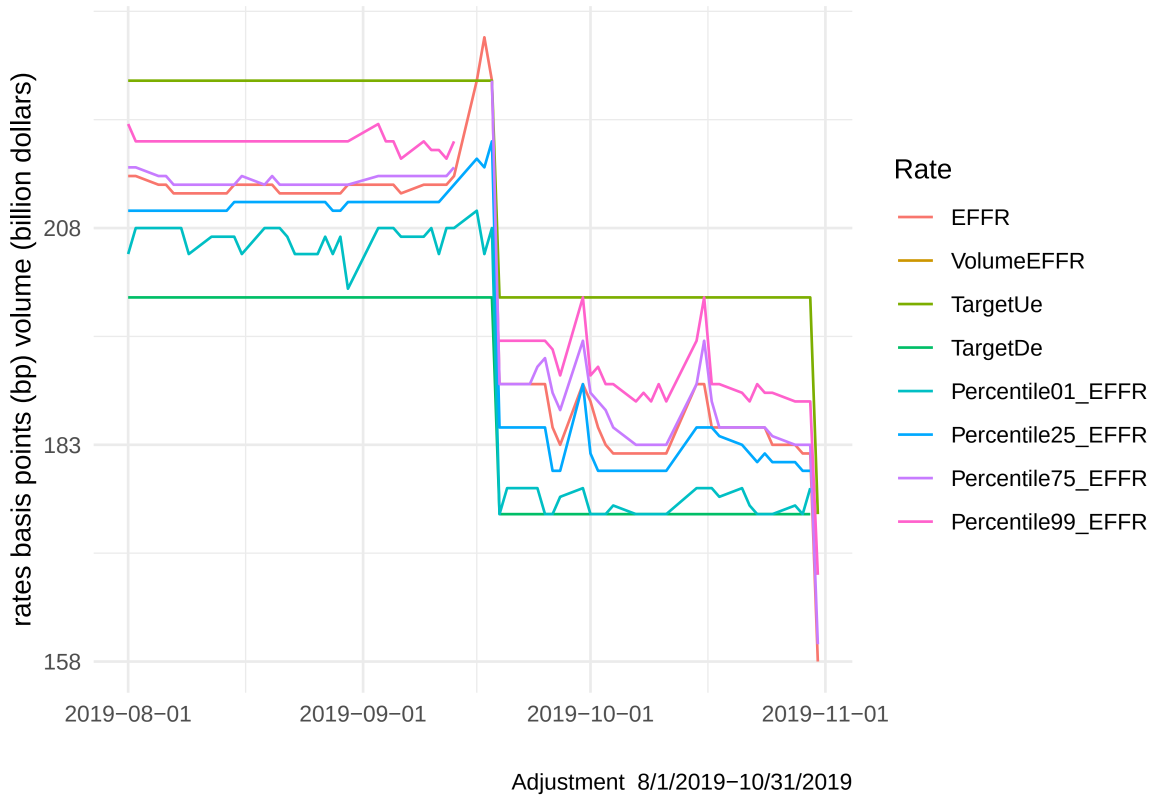

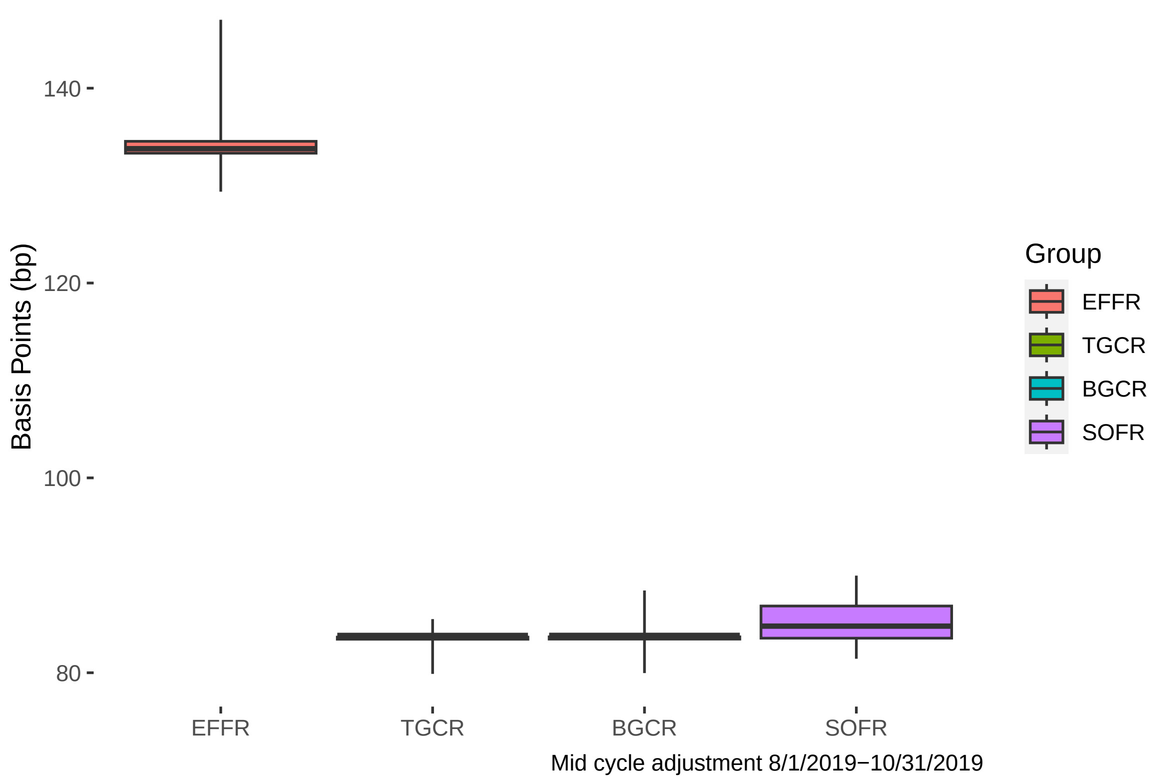

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	EFFR	TGCR	BGCR	SOFR
Rate	200.09	206.30	206.34	208.22
Volume	66.84	466.22	492.47	1151.00
Upper target	212.89			
Lower target	187.89			
Percentile_01	192.08	191.66	191.80	196.47
Percentile_25	197.25	205.62	205.62	206.00
Percentile_75	201.91	206.92	206.98	216.53
Percentile_99	209.75	214.36	225.80	237.73

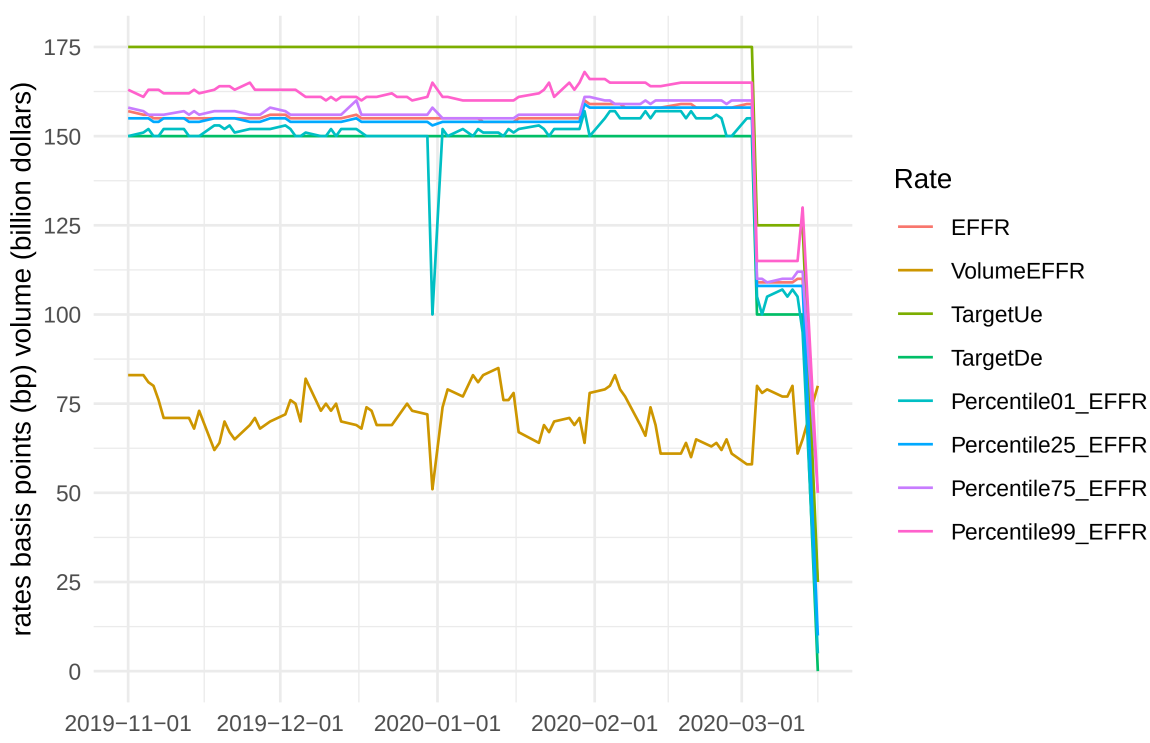
Table 10: Adjustment 8/1/2019-10/31/2019

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:42 2024

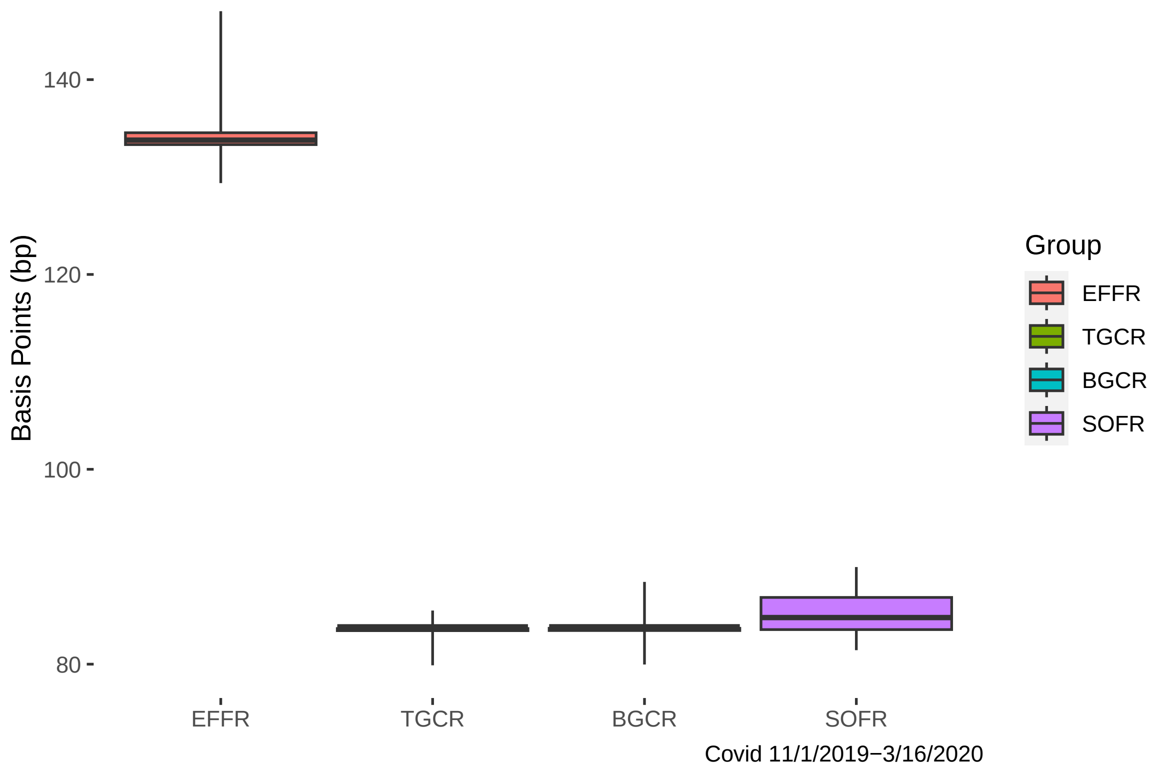
	Category	Median	IQR	RANGE	VOLUME
1	EFFR	183.59	12.84	146.05	1468.70
2	TGCR	248.51	6.71	274.56	1491.08
3	BGCR	254.84	15.29	300.67	1529.02
4	SOFR	369.33	25.88	954.53	2215.95

Table 11: Adjustment 8/1/2019-10/31/2019

The pandemic
The 99th percentile represents the outlier from the March 20, 2020 dash for cash are outside the FOMC target rate (Figure **??**).[CHECK ON DROP end of period All quantiles? beg zlb, check date] The EFFR, median and IQR values are within the FOMC target ranges (the green step function for the lower and upper target rates, TargetDe, and TargetUe) . The median EFFR is 150.46 bp, the IQR 2.35 (Table 13). The average 99th percentile of the EFFR is 157.52 bp (Table 12).



Covid 11/1/2019−3/16/2020



% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:44 2024

	EFFR	TGCR	BGCR	SOFR
Rate	150.46	148.64	148.64	151.19
Volume	71.70	401.74	423.19	1085.60
Upper target	168.96			
Lower target	143.96			
Percentile_01	145.80	142.08	142.30	145.62
Percentile_25	149.53	148.47	148.47	148.71
Percentile_75	151.88	148.78	148.89	156.09
Percentile_99	157.52	153.29	158.32	165.08

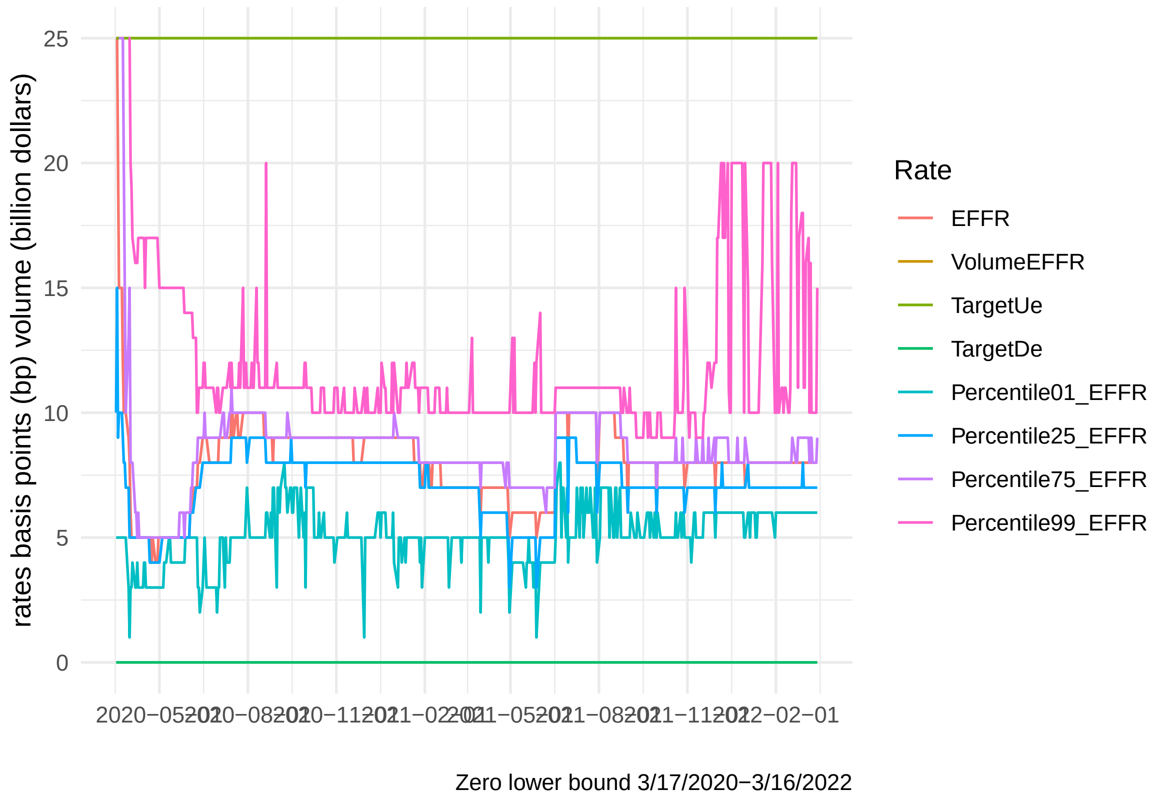
Table 12: Covid 03/17/2022-12/14/2023

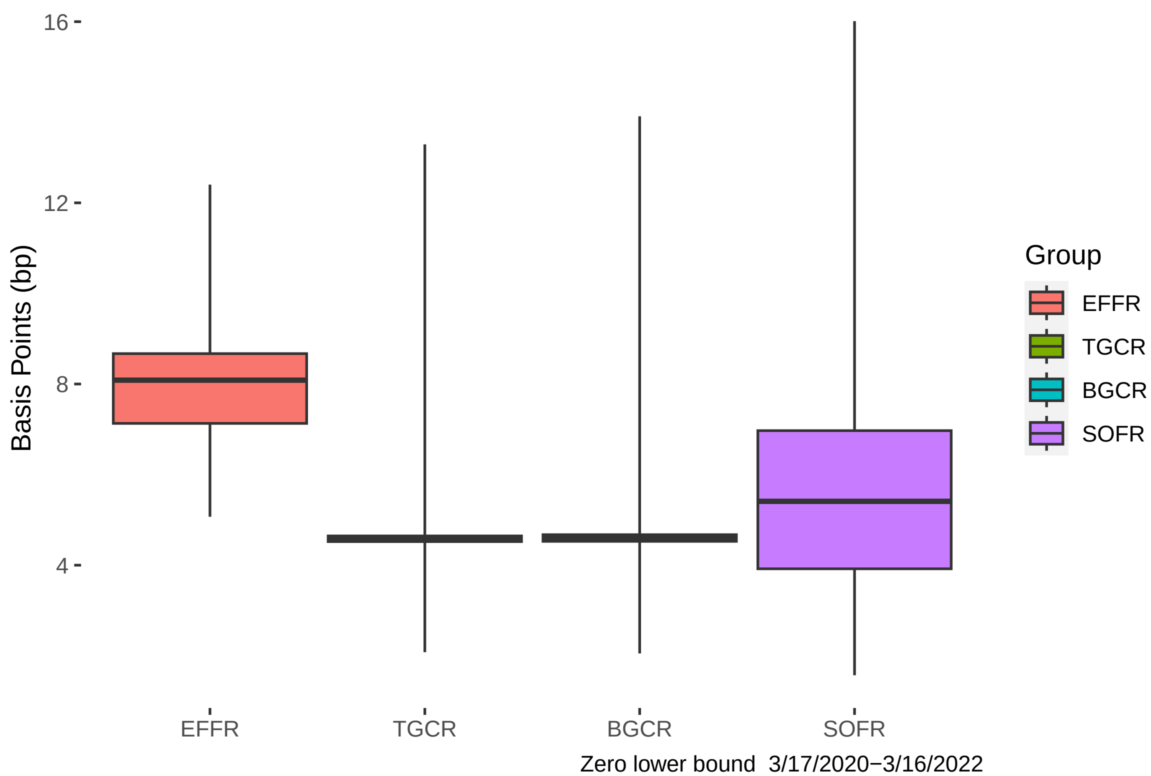
% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:44 2024

	Category	Median	IQR	RANGE	VOLUME
1	EFFR	150.46	2.35	11.71	71.70
2	TGCR	148.64	0.31	11.21	401.74
3	BGCR	148.64	0.42	16.02	423.19
4	SOFR	151.19	7.37	19.46	1085.60

Table 13: Covid 03/17/2022-12/14/2023

The zero lower bound Although no quantile of the EFFR during the zero lower bound is outside the target range of zero to 25 bp, clearly rates were volatile during this period (Figure **??**). The median EFFR is 8.09 bp, the IQR 1.54 (Table 15). Although the average 99th percentile of the EFFR, 12.40 bp, excceds the median, it remains within the FOMC range (Table 14).





and (Figure **??**).

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:45 2024

	EFFR	TGCR	BGCR	SOFR
Rate	8.09	4.59	4.59	5.41
Volume	68.97	353.60	376.32	943.72
Upper target	25.00			
Lower target	0.00			
Percentile_01	5.07	2.08	2.05	1.57
Percentile_25	7.13	4.52	4.53	3.92
Percentile_75	8.67	4.65	4.67	6.97
Percentile_99	12.40	13.29	13.91	16.01

Table 14: Zero lower bound 03/17/2020-03/16/2022

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:45 2024

	Category	Median	IQR	RANGE	VOLUME
1	EFFR	8.09	1.54	7.33	68.97
2	TGCR	4.59	0.12	11.21	353.60
3	BGCR	4.59	0.15	11.86	376.32
4	SOFR	5.41	3.05	14.44	943.72

Table 15: Rate statistics Zero lower bound 03/17/2020-03/16/2022

The Fed's fight to control inflation The median and IQR EFFR are within the FOMC target, but the outliers represented by the 99th percentile of the EFFR exceed the upper FOMC bound for most of 2023 (Figure **??**). The median EFFR is 368.60 bp, the IQR 1.62 (Table 17). The average 99th percentile of the EFFR, 388.81 bp, exceeds the upper FOMC target 385.65 (Table 16).

The EFFR and the IQR are within the FOMC target rates (Figure 8). (Figure **??**).

The rate characteristics during the taming of inflation are shown in (Table 16).

The rate statistics the taming of inflation are shown in (Table 17).

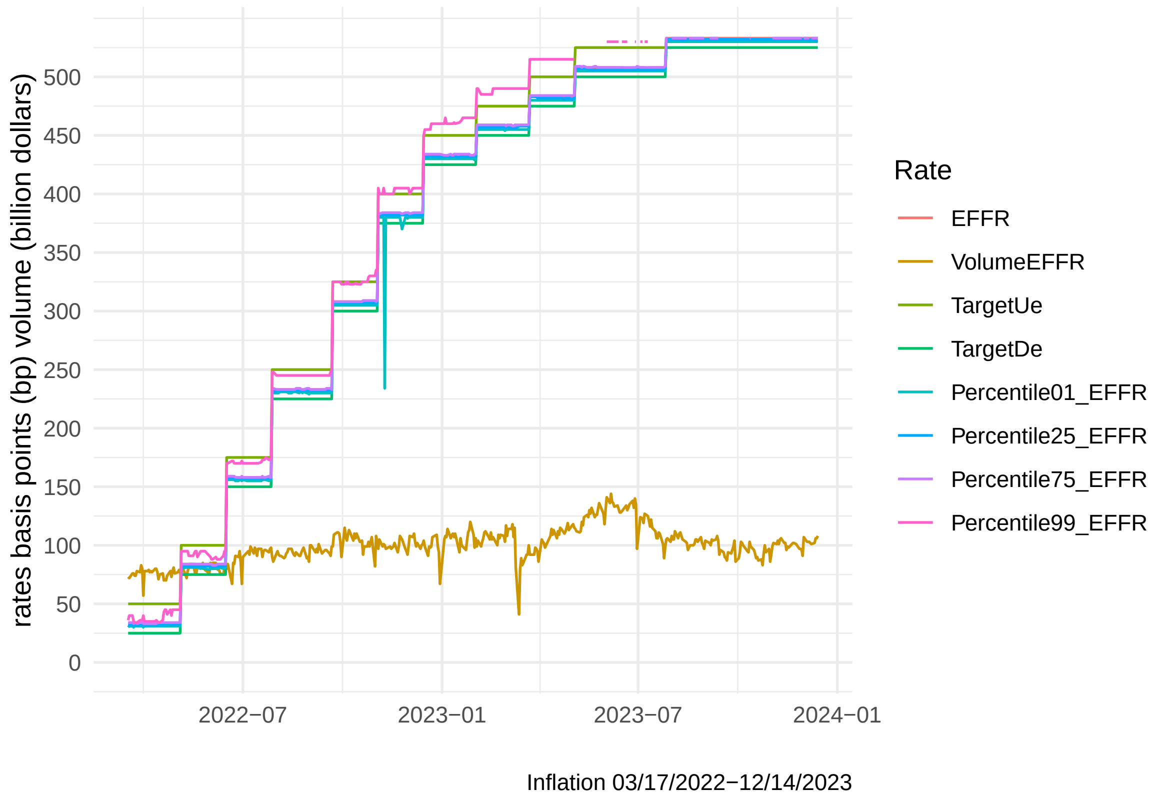
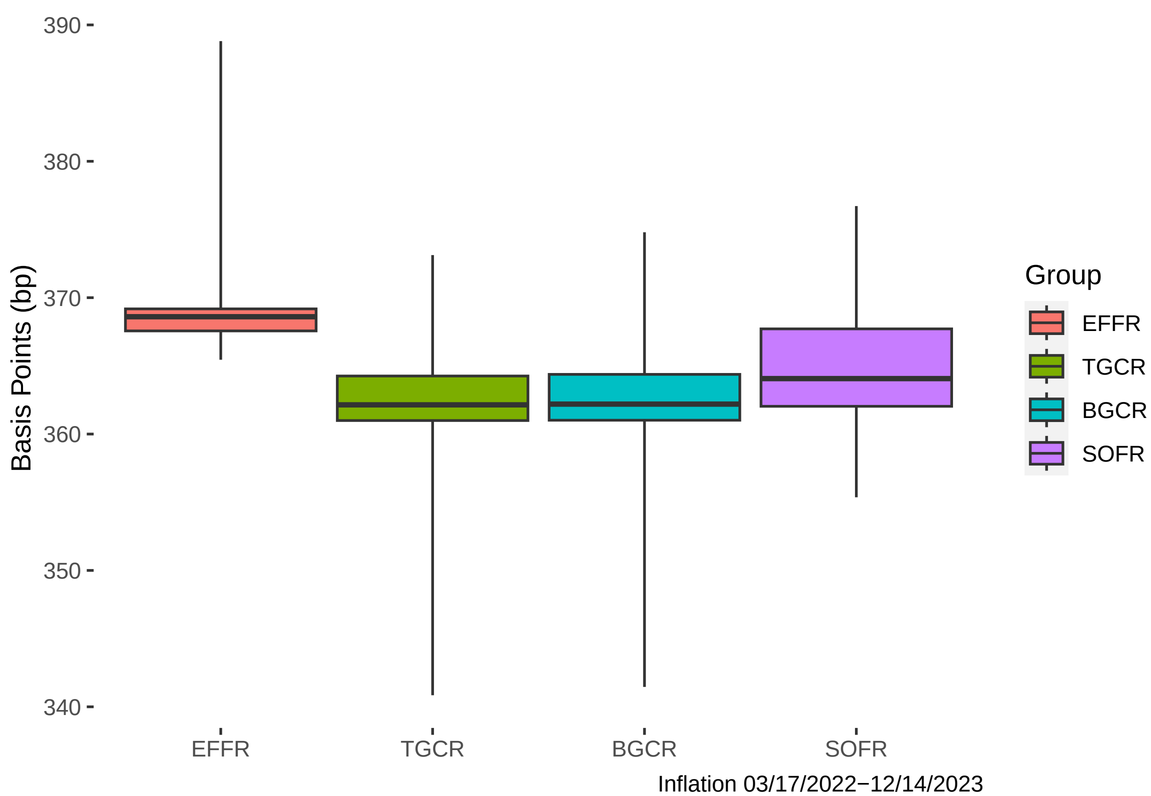


Figure 8: EFFR during inflation period 3/17/2022-12/14/2023



% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:46 2024

	EFFR	TGCR	BGCR	SOFR
Rate	368.60	362.14	362.20	364.07
Volume	99.56	455.92	469.75	1199.94
Upper target	385.65			
Lower target	360.65			
Percentile_01	365.45	340.85	341.46	355.36
Percentile_25	367.56	360.99	361.01	362.03
Percentile_75	369.18	364.26	364.38	367.71
Percentile_99	388.81	373.12	374.80	376.72

Table 16: Taming inflation 03/17/2022-12/14/2023

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:46 2024

	Category	Median	IQR	RANGE	VOLUME
1	EFFR	368.60	1.62	23.36	99.56
2	TGCR	362.14	3.26	32.27	455.92
3	BGCR	362.20	3.36	33.34	469.75
4	SOFR	364.07	5.68	21.35	1199.94

Table 17: Rate statistics Taming inflation 03/17/2022-12/14/2023

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:46 2024

	Sample	Normalcy	Adjust	Covid	Zlb	Inflation
EFFR	156.97	133.79	183.59	150.46	8.09	368.60
TGCR	132.83	83.83	248.51	148.64	4.59	362.14
BGCR	132.85	83.84	254.84	148.64	4.59	362.20
SOFR	134.08	84.78	369.33	151.19	5.41	364.07

Table 18: Median of rates during policy regimes

(Table 18)

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:46 2024

	Sample	Normalcy	Adjust	Covid	Zlb	Inflation
EFFR	1.56	1.22	12.84	2.35	1.54	1.62
TGCR	0.92	0.22	6.71	0.31	0.12	3.26
BGCR	0.96	0.23	15.29	0.42	0.15	3.36
SOFR	4.20	3.30	25.88	7.37	3.05	5.68

Table 19: Interquartile range (IQR) of rates during policy regimes

(Table 19)

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:47 2024

	Sample	Normalcy	Adjust	Covid	Zlb	Inflation
EFFR	15.99	17.65	146.05	11.71	7.33	23.36
TGCR	13.86	5.62	274.56	11.21	11.21	32.27
BGCR	16.11	8.48	300.67	16.02	11.86	33.34
SOFR	14.51	8.53	954.53	19.46	14.44	21.35

Table 20: Range of rates during policy regimes

The average median rates and percentiles illustrate the tendency of other rates to cluster around the EFFR, and the clustering and outliers present in these reference rates.

Median daily reference rates The difference in the central tendency as measured by the median rate, changes dramatically over different policy episodes. A measure of central tendency, the median of the reference rates EFFR and money market rates (Table 18) illustrate how closely money market rates track the policy rate EFFR. The change in median rates during different episodes demonstrate the how their central tendency changes with monetary policy. Average median rates for the sample are 157 bp for the EFFR, and some 133-134 bp for the money market rates and SOFR.

The sample EFFR 157 bp drops to 134 bp during the normalization period, 184 bp in the adjustment period bp, 150.46 bp during covid,8.09 bp the zero lower bound, and 369 bp during the inflation fighting period.Rates hover near zero from March 2020 to March 2022 during the zero lower bound. Median rates during the inflation episode increased over 233 percent of the the sample average as the Fed raised the FFR in 25 or 50 basis point to tame inflation. Rates rose steadily from ? bp March 2022 to 533 bp in December 2023 some 235 percent of the sample median rate

The IQR and range provide more information about the series, how close they stay to their median values and also the extreme values characteristic of short rates (@ref(tab:IQR of rates during policy regimes)).

Variability how rates cluster around their median, IQR Small interquartile range (IQR) values are evidence that the EFFR and the money market rates, with the exception of SOFR, cluster more tightly around their median values for the sample as a whole (Table 19). For the sample, the IQR is 1.54 bp for the EFFR, and under one bp for the money market rates. For different policy episodes the IQR is under 0.12 to 0.23 during normalcy and the zero lower bound, more disperse, over 1 bp during the adjustment periods and over 3 bp during the inflation episode. Boxplots show the IQR, the location of the median, and tails for the outliers.

SOFR exhibits the greater variability; for the sample as a whole, IQR for SOFR is a high 4 bp. The dispersion of SOFR is even more diverse among policy regimes. SOFR rates have the largest spread around the median rate, reaching over 10 bp during the adjustment period. SOFR is more tightly clustered around its median during normalcy, 3.30 bp and the zero lower bound 3.05 bp, but 7.37 bp during covid and 5.68 bp during inflation. Concoda reports [reference] in February 2023, some 25% of repo trades were based on SOFR, a trillion dollar volume giving the Fed greater influence in global finance [check this claim from concoda]. NYFed data reveal SOFR rates to attain the largest spread in outliers in the tri party or bilateral repo [check].

Outliers The range of the data, the 99th and first percentile, is the spread from the lowest to the highest rates. More sensitive to outliers, the range represents 2 percent of the data, showing the magnitude of outliers under different policies (Table 20). The higher the range, the higher the variability. The spread outliers in the sample for all rates is 14 to 16 bp (bottom panel Table). During normalcy, the spread in money market rates and SOFR is 6 to 8 bp; the EFFR a higher 18 bp. Outliers soar during the period of adjustment, a spread of 18 bp, the EFFR reached 146 bp, the money market rates spread of 23- 34 bp, outliers reaching 275-300 bp. SOFR has the highest variablity, a spread of 42 bp, reaching a whopping 954 bp. The spread of outliers during covid and the zero lower bound are lower than the sample range. Spreads of extreme rate vaues during the zero lower bond are lower than the sample, 7-14 bp, some 11 to 12 bp for the money market rates TGCR and BGCR 7.33 for the EFFR, and 14.44 for SOFR. The spread 21 to 33 bp in outliers occurs during the Fed's attempt to contain inflation. some 23 basis points for the EFFR, the money market rates TGCR and BGCR 32-33 bp, and SOFR 21 bp. Again SOFR shows greater variability in all episodes.

Volatility Heteroskedasticity of overnight rates, here measured as log percent changes in rates, is plus of minus 0.5 percent from 2016 to 2020. Extreme values during the periods of the pandemic and the zero lower bound; from 2020 to 2022, the percent change in rates varies plus or minus 2 percent. then tapers off as the Fed began its fight to contain inflation in 2023, within plus or minus 2 percent (5

ADD volatility by episode

Volume Daily volume in money market rates TBGR $297 billion,and BGCR $311 billion, almost quadruple the transactions in the EFFR: $79 billion. SOFR transactions, $754 billion per day, dwarf trading in all other overnight reference rates.

3.4 Important arbitrage opportunities in overnight reference rates

Under the corridor system that implements the ample reserves, the Fed's setting of the IORB and O/N RRP establish the ceiling and floor within which the Fed manages the range of the FFR.

IORB-EFFR The EFFR represents the cost of interbank borrowing. The difference between the EFFR and IORR presents arbitrage opportunities for banks. Banks can borrow funds at a lower EFFR and deposit the funds for a higher IORB rate, making a profit on the spread.Historically, the IORB has been higher than the EFFR. A narrowing IORB/EFFR spread indicates tight supply of funds in the market and little room for arbitrage, which can lead to an outflow of excess reserves from the banking system. https://libertystreeteconomics.newyorkfed.org/2023/10/whos-borrowing-and-lending-in-the-fed-funds-market-today/

SOFR The SOFR is an influential interest rate banks use to price U.S. dollar-denominated derivatives and loans. The daily SOFR is based on transactions in the Treasury repurchase market. Benchmark rates such as the SOFR are essential in derivatives trading—particularly interest-rate swaps, which corporations and other parties use to manage interest-rate risk and to speculate on changes in borrowing costs.SOFR now covers 25% of daily repo volumes, equalling around $1 trillion, while the number of repos traded daily worldwide totals around $4 trillion. The size of the Eurodollar system, meanwhile, has shrunk dramatically. https://www.concoda.com/p/the-silent-monetary-revolution

Arbitrage opportunities exist to invest in repo when SOFR exceed IORB, the interest banks can receive on deposits with the Fed https://www.cmegroup.com/education/articles-and-reports/trading-us-money-market-spreads-with-sofr.html
An IORB setting that lies near the prevailing level of market repo rates is likely to drive swings in the decisions by which banks choose where to park idle reserve balances, thereby amplifying daily swings in SOFR. SOFR can and frequently does exhibit more day-to-day volatility than survey-based short term interest rates (STIR) benchmarks. https://www.cmegroup.com/education/articles-and-reports/trading-us-money-market-spreads-with-sofr.html

ON RRP and TBills Money market mutual funds (MMFs) have been a major lender in the ON RRP facility. However, the supply of U.S. Treasury bills (T-bills) influences use of ON RPP. Since MMFs cannot hold securities with a remaining maturity greater than 397 days, T-bills are a desireable investment option. MMFs' demand for Treasury securities has grown significantly since October 2016, when the Securities and Exchange Commission (SEC) implemented an important reform of the MMF industry; this reform led to an increase in assets under management of more than $1 trillion for government MMFs—a type of MMF that can only hold Treasury securities, agency debt, or repurchase agreements collateralized by these assets. https://libertystreeteconomics.newyorkfed.org/2023/11/treasury-bill-supply-and-on-rrp-investment/ The supply of TBills affects the decision of money market mutual funds (MMFs) to invest in the ON RRP. When Tbills are scarce, MMEs increase their investment in the ON RRP as in January 2021 to around $2.6 trillion at the end of December 2022. When the supply Tbills is abundant, the reverse.

After the resolution of the latest debt ceiling debacle in June 2023, however, the U.S. Treasury once again issued a deluge of Treasuries into the market, ending the safe asset deficit. The RRP balance had finally peaked, initiating the RRP drain https://www.concoda.com/p/the-reverse-repo-endgame

With 3 month Tbills paying over 5 percent interest, the ON RPP has fallen to its lowest level. After the Fed's largest liquidity injection on record, Concoda predicts the "excess cash" era is coming to an end. As the RRP balance reaches zero, the dynamics in the repo market are about to transform Concoda predicts the return to "excess collateral".

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(Figure 9.

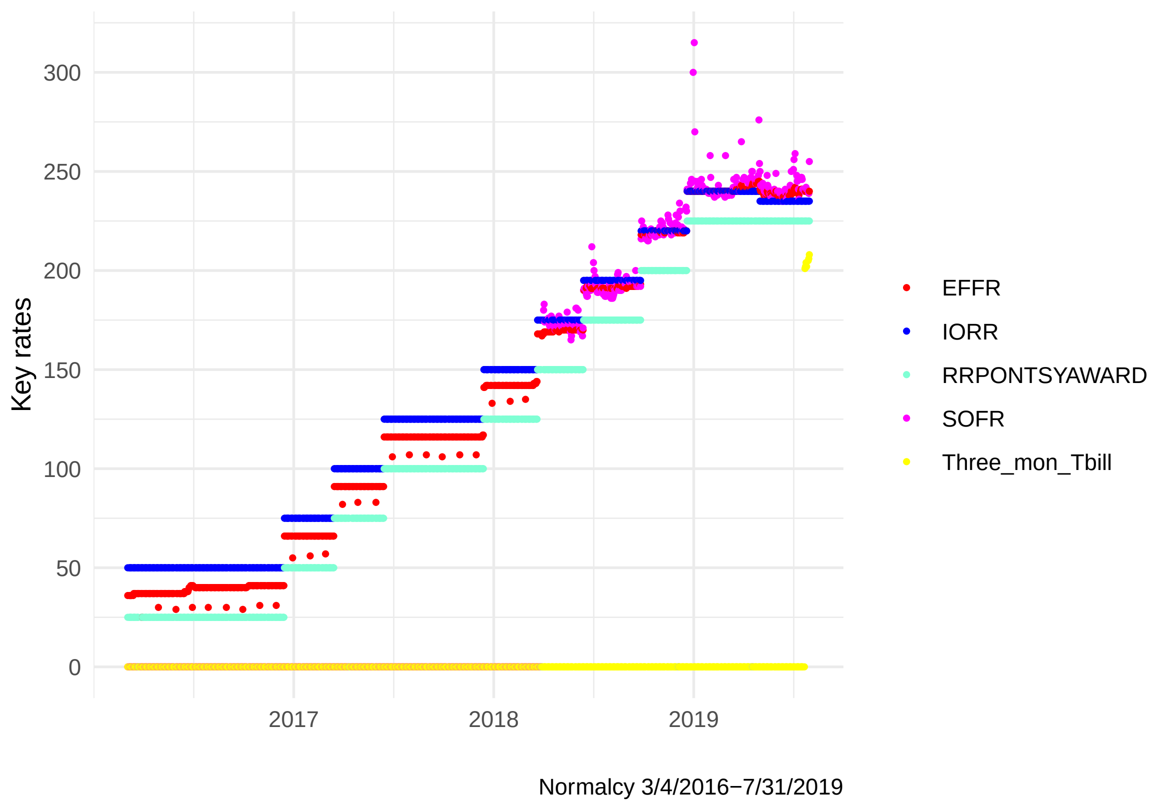


Figure 9: Key reference rates: Normalcy 3/4/2016-7/31/2019

(Figure 10.

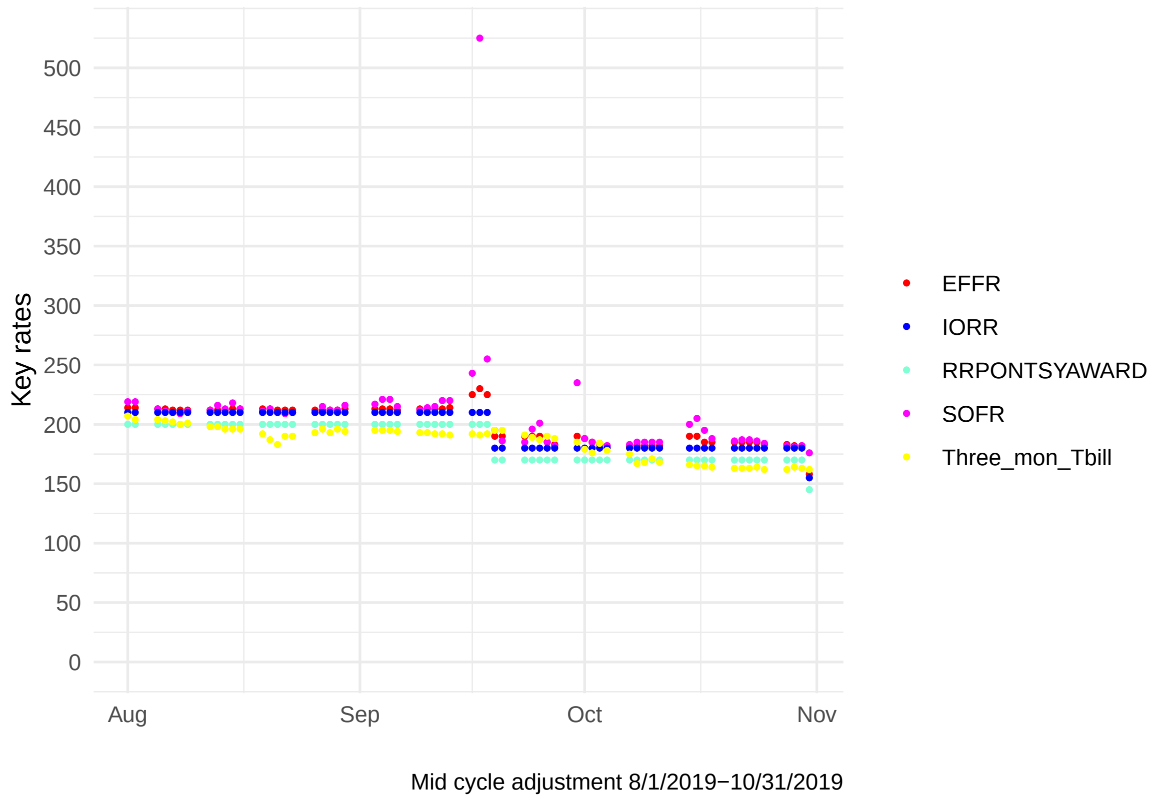


Figure 10: Key reference rates: Adjustment 8/1/2019-10/31/2019

(Figure 11.

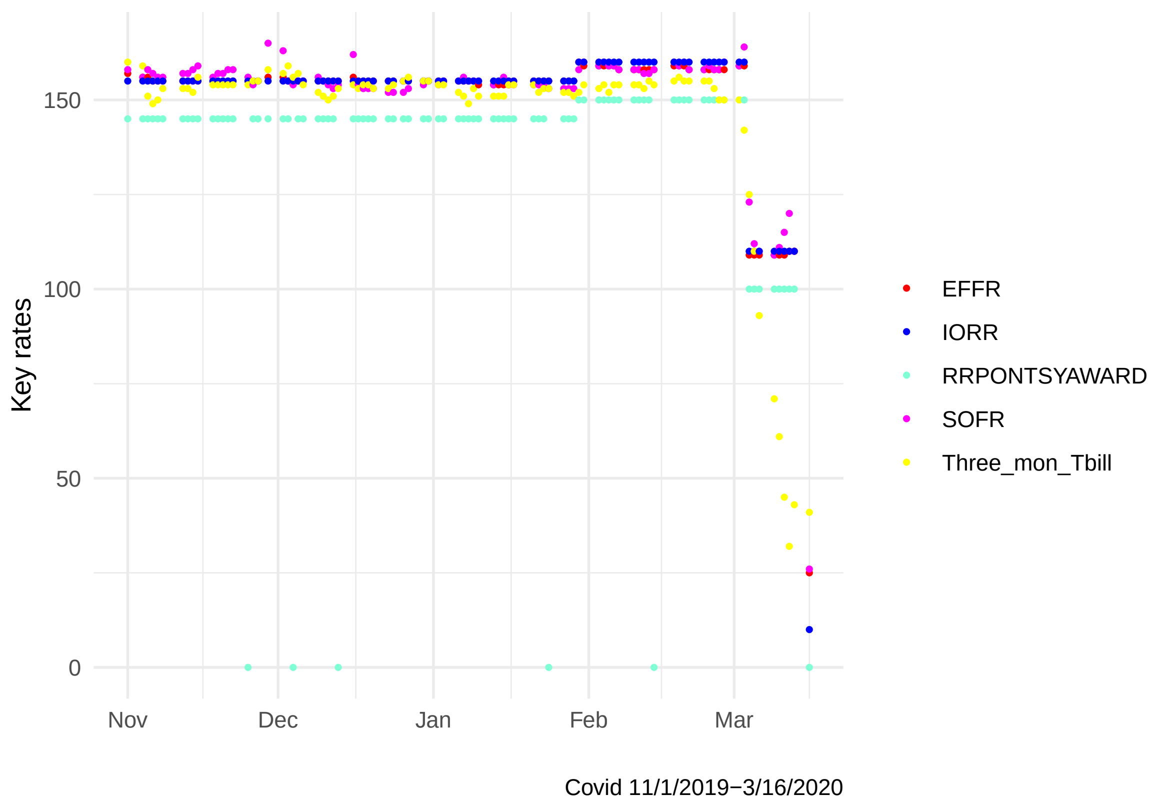


Figure 11: Key reference rates: Covid 11/1/2019-3/16/2020

(Figure 12.

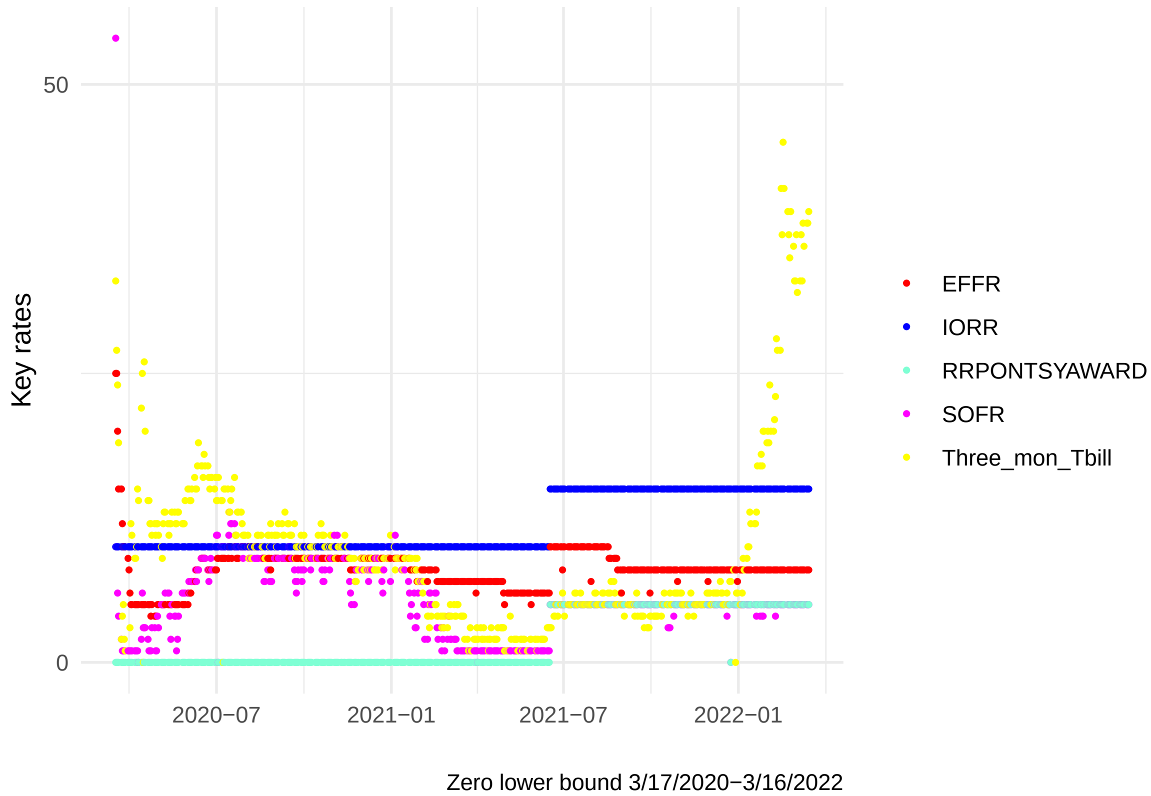
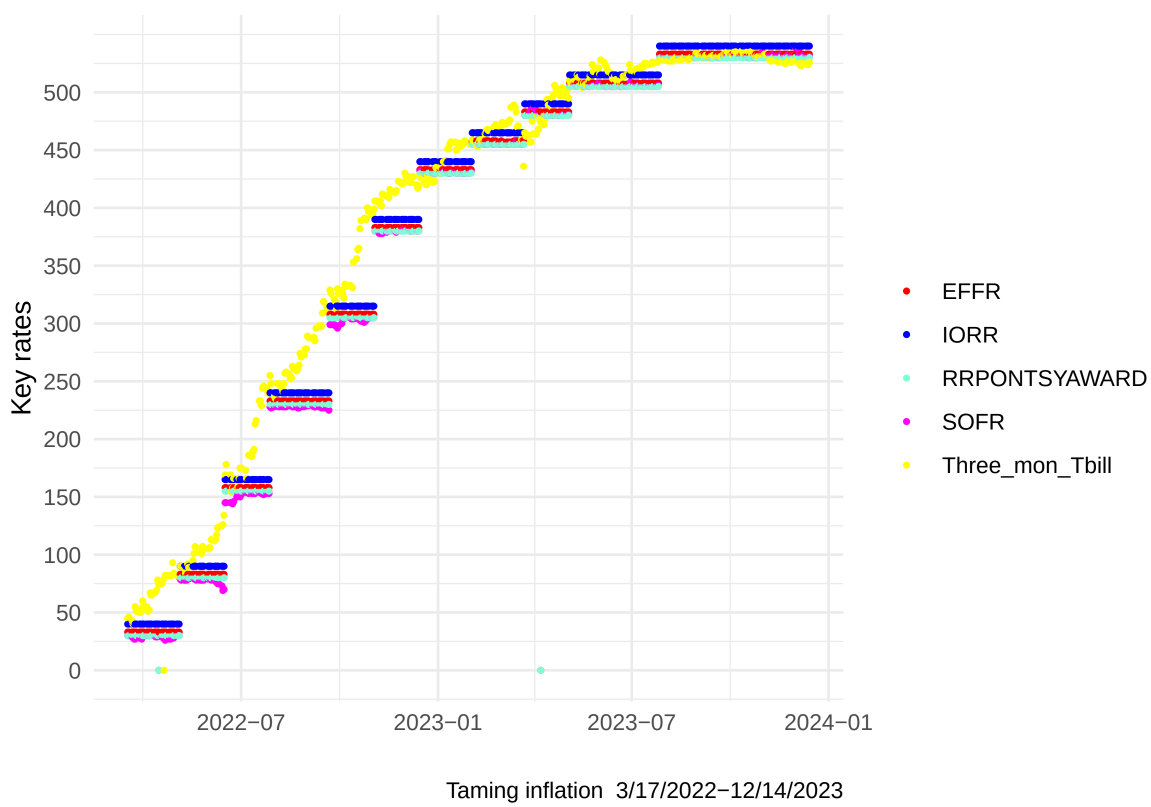


Figure 12: Key reference rates: Zero lower bound 3/17/2020-3/16/2022

(Figure ??.



Monetary policy during the sample period 2016-2023 Before the Great Financial Crisis (GFC) of 2008, Federal Reserve implemented monetary policy by managing the Federal funds rate through open market operations (OMO), trading reserves and securities in the interbank Federal Funds market. To stabilize the economy, the Fed responded to the GFC with large scale asset purchases (LSAPs) from 2008 to 2014. LSAPs and Quantitative easing (QE),QE1, QE2, and QE3, funded by US Treasury sale of Treasury bills, resulted in excess liquidity. The increased reserve balances at the Fed from large part of its SOMA Treasury holdings swamped reserves, so that banks had no need to borrow in the Fed Funds market. From 2010 to late 2019, reserves went through a full expansion-contraction cycle. Again in early 2020, reserves grew from $$$$8 trillion from 2010 and 2019 to $19 trillion (2014 and 2021). ADD [2022,2023?]

To regain control over the FFR, the Fed experimented with with different policies.

October 1, 2008, Congress gave the Fed the power to pay interest on reserves (IORB) on funds banks deposit into their reserve accounts at the Fed. In 2013, to address the post GFC build up of excess liquidity, the Federal Reserve introduced the overnight reverse repurchase facility (ON RRP). The IORB and the ON RRP have become the Fed's tools for interest rate control.

The FOMC adopted target range in 2018. In 2019 the Fed adopted the ample reserves regime to manage the Fed Funds rate within the target range. The administrative rates, the IORB and ON RRP created a corridor system within which Fed manages the FFR within the FOMC target range. The Fed temporarily intervenes in repurchase (repo) and reverse repo markets to offset high frequency liquidity shocks in order to keep the FFR close to target. Repurchase agreements drain reserves from the system and raise the FFR. Reverse repo purchases of assets by the Fed add reserves and lower the FFR.Together these administrative rates create a floor system for managing the FFR. IORB is the ceiling and the ON RRP rate the floor. No bank would lend at rates lower than the IORB nor borrow at rates higher than the ON RRP rate.

The reverse repurchase facility Fed opened its O/N RRP (reverse repo) facility in 2013 after the GRC to absorb the excess liquidity. QE drove the Fed Funds rate below the Fed's target range. The Overnight Reverse Repo Program (ON RRP) allows eligible counterparties to lend excess funds to the Fed through repo transactions, ensuring that repo rates remain close to or above the ON RRP rate. During periods of high reserves, the reverse repo facility takes up reserves when banks no longer want to take on additional reserves and reducing deposit rates and other funding.

3.5 The Fed's involvement in repurchase markets

Repurchase and reverse purchase transactions

since the 1920s, The Fed used repo transactions to manage the reserves held by commercial banks with the Fed. In the current ample reserves regime,the Fed offsets liquidity shocks with repurchase (repo) and reverse repo transactions to keep the federal funds rate within the FOMC target range. The New York Fed's Open Market Trading Desk (the Desk) is authorized and directed by the Federal Open Market Committee (FOMC) to conduct repurchase agreement (repo) and reverse repo transactions. These open market operations support effective monetary policy implementation and smooth market functioning by helping maintain the federal funds (fed funds) rate within the FOMC's target range. Repo operations became the Fed's primary means of adjusting bank reserves.

The Standing Repo Facility (SRF) After the Fed reduced its balance sheet built up after quantitative easing (QE), repo rates. the FFR, and FX swap rates spiked in 2019, the FFR exceeding the Fed's upper target rate. The Fed initiated the Standing Repo Facility (SRF) as low bank reserves constrained dealer balance sheets, leading to cash shortages and a segmented repo market. The SRF lets primary dealers and other approved counterparties borrow cash from the Fed, secured against U.S. Treasuries. The Fed transformed the SRF into a permanent facility.

Other changes The central banks continued to change their overall frameworks for controlling short-term interest rates. The FOMC reference rate changes from Libor to SOFR,was one such policy change.

–>

3.6 FOMC rates changes, monetary regimes, and events over the seven year period, 2016-2023

Candidate shocks occurring during the seven year period of our sample 2016-2023 (Table @ref{table_fomc}) include FOMC rate and administered rate changes, different policy experiments, events such as the March 2020 dash for cash, and macroeconomic announcements. Changes in the Fed funds rate and the administered rates IORB and the reward rate ON RRP are one source of shocks to overnight reference rates. The shocks (Table @ref{table:FOMC rate changes 2016-2023}) encompass changes in both policy and administered rates- FFR, IOR, ONRRP (same as changes in RRF?) and classify these changes under episodes). I have included events like US Treasury sales and macro financial shocks like the repo shock in 2019 and the dash for cash event in March 2020. I have included observations of US Treasury debt issuance and events such as the repo apocalypse in 2019 and the dash for cash of March 2020.

However, there are many compendia of shocks to draw on. I will evaluate each one when choosing methodology to model the volatility of the FFR and repo market rates.

The Romer and Romer (2023) narrative approach to identifying macroeconomic evidence into a statistical framework limits to monetary shocks that are unrelated to current or prospective real economic activity. This approach would exclude shocks such as policy changes such as QE, LSAP, and forward guidance or events such the spike in repo rates in 2019 or the March 2020 dash for cash.

Beginning with Campbell et al. (2012), there is a literature that identifies monetary policy shocks from changes of financial asset prices in a narrow time window around Federal Open Market Committee (FOMC) announcements. The authors distinguish between Odyssean forward guidance, which publicly commits the FOMC to a future action, and Delphic forward guidance, which merely forecasts macroeconomic performance and likely monetary policy actions.

The argument is that prior to FOMC announcements, asset prices reflect the consensus view on the state of the economy and the Fed's expected response to it. Afterwards, asset prices incorporate unexpected news conveyed in the announcement. News can include different structural shocks that may affect the economy differently - the current fed funds rate or its future path, asset purchases, or the Fed's view on the state of the economy.

Jarocinski (2022) estimates a wealth of structural shocks underlying the reactions of financial market to FOMC announcements. He estimates high-frequency reactions of financial variables, such as interest rates and stock prices, to FOMC announcements. Exploiting these fat tails or excess kurtosis} implies that these data may contain information about the nature of the underlying structural shocks.

His baseline model expresses surprises, high-frequency reactions to FOMC announcements, in near-term fed funds futures, 2 and 10-year Treasury yields and the S&P500 stock index as linear combinations of four Student-t distributed shocks}. These four shocks ex post have natural economic interpretations: 1. the standard monetary policy shock raises the near-term fed funds futures, with a diminishing effect on longer maturities, and depresses stock prices. 2. The (Odyssean) forward guidance shock increases the 2-year Treasury yield the most and depresses the stock prices. 3. The asset purchase shock increases the 10-year Treasury yield the most and plays a large role in some of the most important asset purchase announcements. 4. Delphic forward guidance shock (Campbell et al. 2012) has a similar impact on the yield curve as the Odyssean forward guidance shock, but triggers an increase, rather than a decrease, in the stock prices.

Monika Piazzesi (2005) follows the approach to exploit information from financial markets. Both financial markets and the FOMC watch one another. The FOMC extracts information about the economy from the yield curve . In a continuous-time model of the joint distribution of bond yields and the FOMC interest rate target for the FFR in a linear-quadratic jump-diffusion model. With high-frequency data she provides information about the exact timing of FOMC meetings. The short informational lag before Fed's policy decision, information available right before the FOMC meeting start provides a recursive identification scheme that turns the target forecast from right before the Federal Open Market Committee (FOMC) meeting into a high-frequency policy rule and the associated forecast errors into policy shocks.

(Kerssenfischer, Schmeling (2023) compile a vast database from to 2020 of news that impact asset prices: macroeconomic data releases, monetary policy announcements, and ad hoc news. They state they will make the data available soon.

They regress the second moment of asset returns y, bonds and stocks, on dummy variables representing news sources, time fixed effects such as days, and lagged volatility measures..

$$y_t^2 = \alpha + \sum_{i=1}^{k} \beta_i D_{i,t} + \lambda_j FE_{j,t} + vol_{k,t} + \epsilon_t$$

They attribute to news, the fraction of total market movements Ω:

$$\Omega(k) = \sum_{i=1}^{k} \frac{E[y_t^2|D_{i,t}=1]P(D_{i,t=1}}{E(y^2)} \Omega(k) = \sum_{i=1}^{k} \frac{\beta_i P(D_{i,t=1}}{E(y^2)}$$

where k is the rank of each news release for a given asset (for most assets, k = 1 is the US employment report. The *betas* correspond to estimates of the effect of news i on the conditional second moment. Weighing each coefficient by the frequency of releases and summing over all news gives the second-moment share explained by all news. Since E[y] $\approx$ 0 in tight event windows as discussed above, this measure is very close to a variance share which they label R^2.

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## Warning in notes_with_valid_dates$Date <- notes_with_valid_dates: Coercing LHS
## to a list
```

% latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:53 2024

	Date	Event
March 3, 2020	18324.00	Fed set rate of purchases
March 11, 2020	18332.00	Fed updated guidance
March 15, 2020	18336.00	Fed began tapering
March 16, 2020	18337.00	Fed doubled tapering speed
April 1, 2020	18353.00	Fed emergency rate cut
June 1, 2020	18414.00	WHO declares Covid-19 pandemic
August 28, 2020	18502.00	Fed slashes rates to zero
December11, 2020	18607.00	Stock market crash
July 28, 2021	18836.00	Highest US unemployment since 1948
November 1, 2021	18932.00	Fed announces new strategy
December 1, 2021	18962.00	Fed holds rates steady
January 26, 2022	19018.00	Powell states labor market conditions
February 24, 2022	19047.00	Russia invades Ukraine
March 16, 2022	19067.00	Fed makes first rate increase since 2018
May 5, 2022	19117.00	Fed increases interest rates
June 1, 2022	19144.00	Inflation peaks
June 16, 2022	19159.00	Fed raises rates
July 28, 2022	19201.00	Fed hikes rates
September 22, 2022	19257.00	Fed delivers another rate increase
November 3, 2022	19299.00	Fed increases rates
December 15, 2022	19341.00	Fed raises rates
February 2, 2023	19390.00	Fed adds another increase
March 23, 2023	19439.00	Fed increases interest rates
May 4, 2023	19481.00	Fed hikes another increase
July 27, 2023	19565.00	Fed delivers final increase of 2023

Table 21: Important Events Timeline

4 Methodology

[Add percent change sigma here and comment on results]

I plan to explore methods proposed by Piazzesi, Bezoni et al and Jarocinski.

I first run a vector sutoregression on the EFFR and repo market rates to gain insight into mean reversion over one day, t to t+1,and clustering. I re-estimate Bertolini, Bertola, and Prati's empirical model of the volatility of the EEFR and compare the results.

4.1 VAR of daily rates EFFR, TGCR, BGCR, SOFR

The Fed's policy rate, the EFFR is mean reverting at a daily frequency, but changes little in response to changes in repo rates TGCR, the tri party repurchase rate. and BGCR the bilateral market rate, some 0.14 basis points (bp). In response to changes in the EFFR, the money market rates change by around 2 bp, the TGCR positively 2.1 bp, the BGCR a negative 2.02 bp. They respond to changes in own rates and SOFR – TGCR positively, BGCR negatively. SOFR responds very little to changes in the EFFR, a small -.08bp, and increases under one bp to changes in the money market rates TGCR and BGCR.

(Table (22) % latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:53 2024

	EFFR	TGCR	BGCR	SOFR
EFFR	1.00	0.14	0.14	0.14
TGCR	2.10	1.79	1.63	1.19
BGCR	-2.02	-1.77	-1.61	-1.97
SOFR	-0.08	0.84	0.85	1.65
ones_v	0.15	-4.54	-4.55	-4.39

Table 22: Beta sample rates 3/4/2016 to 12/14/2023

[1] 439 [1] 439

```
## Error in eval(expr, envir, enclos): object 'X' not found

## Error in eval(expr, envir, enclos): object 'X' not found

## Error in model.frame.default(formula = log_sd_effr_squared ~ X, drop.unused.levels = TRUE): variab

## Error in eval(expr, envir, enclos): object 'result' not found

## Error in data.frame(..., check.names = FALSE): arguments imply differing number of rows: 1957, 438

## Error in eval(expr, envir, enclos): object 'external_regressors' not found

## Error in h(simpleError(msg, call)): error in evaluating the argument 'x' in selecting a method for

## Error in eval(expr, envir, enclos): object 'external_regressors' not found

## Error in eval(expr, envir, enclos): object 'external_regressors' not found

## Error in eval(expr, envir, enclos): object 'arima_model' not found

## Error in eval(expr, envir, enclos): object 'arima_model' not found

## Error in h(simpleError(msg, call)): error in evaluating the argument 'object' in selecting a metho

## Error in eval(expr, envir, enclos): object 'vcov_matrix' not found

## Error in eval(expr, envir, enclos): object 'arima_params' not found

## Error in h(simpleError(msg, call)): error in evaluating the argument 'x' in selecting a method for

## Error: object 'arima_params' not found

## Error in eval(expr, envir, enclos): object 'arima_params' not found

## Error in h(simpleError(msg, call)): error in evaluating the argument 'object' in selecting a metho

## Error in h(simpleError(msg, call)): error in evaluating the argument 'object' in selecting a metho

             Variable        Coeff           SE bbp_full_Coeff bbp_full_SE
```

1 ar1 0.844725586 0.013027682
2 intercept 1.995289332 0.107038918
3 oneday__beforeholiday 0.090674060 0.132469988 -0.026 0.017 4 threeday__beforeholiday -0.100208356 0.045532230 -0.018 0.008 5 oneday__afterholiday 0.056307993 0.130075255 0.062 0.018 6 endquarter 0.143136334 0.089780256 0.206 0.034 7 endyear 0.108245069 0.173393200 -0.185 0.078 8 Monday -0.002832700 0.061330489
9 Friday -0.013389683 0.023629359
10 fomc 0.009347913 0.005977139
11 fomcindex -0.284634005 0.148983964 0.431 0.05 12 z -0.700228944 0.221628438
13 nt 0.049702753 0.091452890
14 absnu 0.016534819 0.010158805
15 nu -0.002099820 0.006963208
bbp1994___Coeff bbp1994___SE 1 0.6 0.038 2
3
4
5
6 2.081 0.181 7 2.913 0.331 8
9
10
11 0.713 0.262 12 1.24 0.465 13 0.668 0.195 14 0.718 0.069 15 0.276 0.042 % latex table generated in R 4.3.2 by xtable 1.8-4 package % Thu Aug 22 20:24:53 2024

	Variable	Coeff	SE	bbp__full__Coeff	bbp__full__SE	bbp1994___Coeff	bbp1994___SE
1	ar1	0.84	0.01			0.6	0.038
2	intercept	2.00	0.11				
3	oneday__beforeholiday	0.09	0.13	-0.026	0.017		
4	threeday__beforeholiday	-0.10	0.05	-0.018	0.008		
5	oneday__afterholiday	0.06	0.13	0.062	0.018		
6	endquarter	0.14	0.09	0.206	0.034	2.081	0.181
7	endyear	0.11	0.17	-0.185	0.078	2.913	0.331
8	Monday	-0.00	0.06				
9	Friday	-0.01	0.02				
10	fomc	0.01	0.01				
11	fomcindex	-0.28	0.15	0.431	0.05	0.713	0.262
12	z	-0.70	0.22			1.24	0.465
13	nt	0.05	0.09			0.668	0.195
14	absnu	0.02	0.01			0.718	0.069
15	nu	-0.00	0.01			0.276	0.042

Table 23: EGARCH (1,1) 3/4/2016 to 12/14/2023 vs Bartolini, Bertola, Prati

4.2 Bertola et al empirical model of the Fed Funds rate

The logic. Daily the Fed injects m_t to keep the FFR close to its FOMC target rate r_t^*. A zero mean random shock ν_t alters banks' reserves, like Treasury payments and other non bank transactions. Banks may then borrow or lend $b_{i,t}$ in the interbank market at rate r_t. After the market clears, a second zero mean liquidity shock ϵ_t alters banks reserve positions. The dynamics of the FFR r_t reflect banks' update of their daily reserve position. The shape and position of the banks' the FFR as a function of their reserve position fluctuates with the probability distribution of future shocks.

If the Fed intervenes it is with just enough reserves to provide banks with sufficient liquidity m_t to maintain the target FFR r_t^*. The Fed may choose to offset liquidity shocks or not, depending on its preferences for volatility of the FFR or its capacity to intervene. It may choose to let interest rate changes to absorb part of the shock to liquidity.

Alternatively liquidity shocks can be absorbed through changes in interest rates. If the Fed changes ints target rate in response to shocks that also affect reserves, e.g. money demand, inflation, output, then these shocks will spill over into higher rates.

For comparison with other methods, I replicate Bartolini, Bertola, Prati (2000) empirical model of the volatility of the Federal Funds rate. Their objectives were to evaluate the time series properties of the Fed Funds rate: - mean reversion behavior in the Fed Funds - main patterns of volatility in the Fed funds rates.

They note that although overnight wholesale money market rates change in response to monetary policy and other shocks, they quickly revert to changes in the federal funds rate (FFR) or administered rates. Other findings were that the Fed funds rate:

- rises in advance of reserve settlement days
- declines in high rate regimes
- exhibits biweekly periodicity when Fed is perceived as committed to keeping rates close to the target
- falls at the end of the year with variance 17 times larger that that of a typical day
- rises at end of quarters 1,2, and 3 with variance 8 times larger that that of a typical day and falls afterward
- tends to fall before holidays and rise afterwards
- responds positively to penalty rate 1.240 (0.465) in post 1994 perdiod
- increases on FOMC announcements days 0.783 (0.262) in post 1994 period
- Each non trading day raises the variance of the next trading day by 67 percent, post 1994 period

The EGARCH parameters are significant indicating:

- persistence in underlying volatility of liquidity shock
- the distribution of errors, degrees of freedom.of student indicate very fat tails with t 2.94 significantly different than 3 $\rho = 0.747$

Other findings: The variance of the FFR

- rises 0.067 rather falls at the end of the year as in BBP
- rises at end of quarters 1,2, and 3 by a much smaller 0.115 versus 2.08 in BBP
- rises one day before holidays but falls three days before holidays and rises one day after holidays but a much smaller effect whereas Bertolini evidence shows the FFR tends to fall before holidays and rise afterward

Their empirical model of Fed Funds rate is $r_t = \mu_t + \sigma_t \nu_t$ where ν_t is a unit variance mean zero i.i.d error term. ν_t is a random shock that alters reserve balances after the Fed has injected reserves m. In a sense a counterpart to a forecast error of Treasury payments and other non bank flows.

Conditional mean $r_t, \mu_t = E[r_t]$ They include the affect of level shift of changes in the target rate r_t^* on interest rates: $\mu_t = r_{t-1} + \delta_t + \kappa k_t + \iota(r_t^* - r_{t-1}^*)$

Conditional variance $\sigma_t^2 = E[(r_t - \mu_t)^2] = log(\sigma_t^2) + \omega h_t + \xi z_t = \lambda(log(\sigma_{t-1}^2) + \omega h_{t-1} + \xi z_{t-1}) + \alpha|\nu_{t-1}| + \theta \nu_{t-1}$

z_t expresses the target rate as proportion of discount window primary credit rate (DPCredit)

Arima EGARCH results for the variance of the FFR 2016-2023 I replicated the Bertolini et al (2000) model for the variance of daily Federal funds rate data from 2016 through 2023. I eliminated the dummy days for the reserve period Reserve requirements for depositor banks and institutions at the Federal Reserve, since there were no required reserves from 2016 to 2023.

I included their k dummy variables: before and after holidays, end of quarter, end of year I dropped the δ specific to maintenance day, as there were no required reserves during 2016-2023. The calendar effect variables included in the dummy h_t are: - holiday
- oneday_beforeholiday
- threeday_beforeholiday - oneday_afterholiday
- threeday_afterholiday - endquarter

- endyear
- around_qtr
- around_yr
- Monday
- Friday

The response of the FFR to dummies representing individual dates are similar in full sample to the 201-2023 replication?] but have different signs and are very small compared to Bertolini el al post 1994 sample (Table @ref(tab:egarch_bbp_table).

The only agreement among day effects of this 2016-2023 replication with the authors' earlier full sample is

- Quarter end 0.14 vs .206
- Three day before holiday -.10 vs -0.18
- One day after holiday 0.06 vs 0.062

End of year coefficient are positive in the 2016-2023 period, 0.11 vs -0.185 in the earlier full sample

The effect of a target change in the replication is-0.028, in the full sample is 0.431, 0.783 in the 1994 sample

In contrast for the end of year 2.861 and end of quarter 2.081 effects are large compared to the current test

Bartolini estimates show the FFR - responds positively to the penalty rate function 1.240 (0.465) - increases on FOMC announcements days 0.783 (0.262)

During the period 2016-2023, my estimates show the volatility of of the daily EFFR - falls with increases in penalty rate -.7 (0.089) - decreases on FOMC days -0.285 (0.248) - small non trading day increase 0.400 (0.046)

BBP find persistence in the liquidity error ν . Absolute error ν 0.016 (0.745) currently versus 0.718 (0.465) in the 1994 sample Lagged error $\nu + t - 1$ -0.002 (0.076) versus 0.276 (0.042)

The different policy regimes and differing factors in the BBP model provide little information except that day effects are now minimal.

4.3 Candidate models of short rates to explore:

Piazzesi (2005) constructs a continuous-time model of the joint distribution of bond yields and the FOMC interest rate target for the FFR. With high-frequency data in a linear-quadratic jump-diffusion model, she provides information about the exact timing of FOMC meetings. This information can improve bond pricing and ability to identify monetary policy shocks.

Both Federal Reserve and financial markets watch and depend on bond yields. Yield-based information may underlie the FOMC's policy decisions and describes Fed policy better than Taylor rules.The Fed's estimated policy rule reacts to information in the yield curve, especially yields with two year maturities, implying the Fed responds to some medium-run forecast of the economy.The short informational lag before Fed's policy decision, information available right before the FOMC meeting start provides a recursive identification scheme that turns the target forecast from right before the Federal Open Market Committee (FOMC) meeting into a high-frequency policy rule and the associated forecast errors into policy shocks.

Decisions about target moves result in a series of target values that looks like a pure jump process. Estimates reveals increased volatility of interest rates at all maturities in both FOMC meeting days and releases of key macroeconomic data. Macro news releases change the conditional distribution of a future Fed move.

(Andersen, Benzoni,Lund, 2004) model the U.S. short-term interest rate 3 month Tbill with a three-factor jump-diffusion model, a time-varying mean reversion factor, a stochastic volatility factor, and a jump process. The U.S. short-term interest rate is characterized by complex conditional heteroskedasticity, fat-tailed innovations, and pronounced autocorrelation patterns. Stochastic volatility is critical for a good fit. Benzoni et al identify mean reversion of the short rate around a central tendency. The stochastic mean allows a relatively fast mean-reversion of the short rate around a highly persistent time-varying central tendency process. Jumps are integral to the quality of fit and relieve the stochastic volatility factor from accommodating extreme outlier behavior.

The mean drift may be indicative of slowly evolving inflationary expectations (Gara horiz?), time-variation in the required real interest rate, or both.

Estimating the Fed's unconventional policy shocks Javorscinski () estimates the structural shocks that underlie the reactions of financial market to FOMC announcements. While the nature of the shocks is not specified ex ante, ex post the estimated shocks can be naturally labeled as the current fed funds rate policy, an "Odyssean" forward guidance (a commitment to a future course of policy rates), a large scale asset purchase and a "Delphic" forward guidance (a statement about the future course of policy rates understood as a forecast of the appropriate stance of the policy rather than a commitment (Campbell et al., 2012).

5 Results

6 Conclusion

7 References

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<!- Campbell, Jeffrey R., Charles L. Evans, Jonas D. M. Fisher, and Alejandro Justiniano (2012) "Macroeconomic Effects of Federal Reserve Forward Guidance," Brookings Papers on Economic Activity, 1–80, https://EconPapers.repec.org/RePEc: bin:bpeajo:v:43:y:2012:i:2012-01:p:1-80. –>

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article_citation <- list(author = c("Afonso, Gara", "Kyungmin, Kim", "Martin, Antoine","Potter,Simon","Schulhofer-Wohl,Sam"), year = 2004, month = 01, title = "Stochastic volatility, mean drift, and jumps in the short-term interest rate", type = "article")

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8 Appendix