2022

# Securing the Overnight Rates: A Study of Alternative Reference Rates in Illiquid Overnight Tri-Party Repo Markets

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submitted to

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by

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for

Senior Thesis

Spring 2022

25 April 2022

## I. Abstract

Since 2011, the London Interbank Offer Rate (LIBOR) has been on the way out for practitioners and researchers alike due to its manipulation in key bank quotes during the Great Financial Crisis (GFC). This paper intends to examine key rates being introduced as LIBOR substitutes, such as SOFR, BSBY, and Ameribor. Specific to its concern, the paper will back test these rates during times of illiquidity in both their respective markets and the broader financial markets to determine which rates will be able to sustain an abnormal drop in transaction volumes. Furthermore, this paper will try to determine whether a dual benchmark solution is possible in the US Fixed Income markets. Within this paper, tests have specific success in showing a change in relationship during negative volume shocks in underlying volumes for both SOFR and BSBY, but have little success in pairing two rates in a dual benchmark fashion. Further studies that can build off of work in this paper may include volume shocks on other Alternative Reference Rates and other ARRs that may be paired in a dual benchmark solution going forward.

## II. Acknowledgements

I would like to thank my thesis advisor, Prof. Yu, for both the motivation to write this thesis and the continued advice throughout this entire process. Both his lectures and late-night edits to my paper were incredibly useful to the creation of this thesis. I would like to thank Prof. Burdekin for his guidance and suggestion in our Research Methods course. I'd also like to thank Prof. Keil for his intense and diligent approach to Econometrics. Without taking his class, much of the results in this paper would be impossible for me to sort through. I am incredibly grateful to the steady guidance of Prof. Hughson, Prof. McAniff, and Prof. Massoud in both my academic and career development, without which I wouldn't be in the place I am today. Outside of academics, I'm very thankful to my parents, especially the subtle reminder to work when my dad would ask, "What is my mortgage going to look like without LIBOR?" Hopefully, there are some meaningful answers for him here.

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## IV. Introduction

In Fixed Income markets, or financial markets in general, one of the most important numbers for the past three decades has been the London Interbank Offer Rate, or LIBOR. Published daily, LIBOR represented quotations from many of the largest banks in England that answered the question, "At what rate could you borrow funds, were you to do so by asking for and then accept inter-bank offers in a reasonable market size just prior to 11 AM?"[1] The most extreme quotations were then cut out and the middle 50% of quotations were averaged to give a reasonable estimate of interday borrowing costs between banks.

Following a 2008 report in *The Wall Street Journal* that alleged multiple banks fraudulently misquoted their actual overnight financing rates, LIBOR was on its way out of the door in all sections of financial markets. The report claimed that these banks quoted much lower rates than their Credit Default Swap (CDS) spreads indicated, showing that banks would rather not seem as desperate for liquidity as they actually were during the run-up to the Great Financial Crisis[2]. In 2011, LIBOR's exit timeline was announced and committees were created for the replacement of "the world's most important

[1] "ICE LIBOR," ICE LIBOR, accessed January 5, 2022, https://www.theice.com/iba/libor.

[2] Carrick Mollenkamp and Mark Whitehouse, "Study Casts Doubt on Key Rate", *The Wall Street Journal*, May 29, 2008.

financial number"[3]. In the US, the Federal Reserve created ARRC, or the Alternative Reference Rates Committee, to identify alternative rates that could mimic LIBOR in its interbank financing estimates.

The ARRC is composed of many private market participants, all of whom are affected by the transition from USD LIBOR to an alternative rate, whether directly or indirectly. By 2017, ARRC had proposed that the Secured Overnight Financing Rate (SOFR) should take the place of USD LIBOR, effective by the end of 2021. However, not everybody jumped on board with SOFR to begin with. Even in 2022, there are still financial organizations publishing their own rates as an alternative to SOFR, such as Bloomberg and the American Financial Exchange. Although many financial contracts will be using SOFR as a reference rate in the near future, it's still worthy to study the behavior of these new rates as they relate to relative liquidity and health of financial markets.

There are marked differences between LIBOR and its proposed alternatives. For example, LIBOR was quoted on an unsecured basis, meaning that the rate that was shown had an inherent credit risk premium attached to the rate. Since SOFR is derived from repo transaction markets, it is inherently a secured rate (hence, Secured Overnight Financing Rate). Furthermore, a

[3] David Enrich, "Libor: A Eulogy for the World's Most Important Number", *The Wall Street Journal*, https://www.wsj.com/articles/libor-a-eulogy-for-the-worlds-most-important-number-1501170720, July 27, 2017.

major difference between LIBOR and its market-based alternatives is the publication of the rate. Because LIBOR is quoted on the day before, it is referred to as an "in advance rate", meaning that the quotation of the rate on a specific day is for that same day. In contrast, SOFR and other market-based approaches to reference rates must quote their rate "in-arrears", meaning that the quote for that rate was captured in the previous days' markets. For this reason, there's also evidence that LIBOR and its alternatives should behave differently during times of crisis and illiquidity.

The largest of these differences is markedly the market-based approach to this reference rate. LIBOR, as stated before, is a quoted rate that represented a bank's "best estimate" at their overnight borrowing costs. SOFR is constructed through the repo and reverse repo markets. In these markets, participants borrow funds from one another, promising to pay those loans back after a certain amount of time. The loans are collateralized through some sort of security, oftentimes a US Treasury Bond. The borrower promises to buy back the treasury after a certain period of time, with the difference between the first purchase price and the second purchase price becoming the implicit interest rate on that loan. Therefore, these markets are called repo markets (repo standing for repossession). The specific type of repo transactions that construct the calculation of SOFR are tri-party repo

transactions, where the collateral selection, payments, and deliveries are all outsourced to a third party; hence, "tri-party"[4].

There have also been competitor rates to SOFR that their publishers argue work better than SOFR as a LIBOR replacement. For example, the Bloomberg Short-Term Bank Yield Index (BSBY) is constructed through commercial paper (CP) and certificate of deposit (CD) trades between financial institutions to construct an overnight borrowing rate[5]. Because of its similarity to SOFR, such as its in-arrears nature and interday trade calculation, BSBY has become a main competitor to SOFR in LIBOR's replacement. Furthermore, a different rate that wishes to match LIBOR in its interbank, unsecured characteristics is Ameribor, which is published daily by the American Financial Exchange. Ameribor, unlike SOFR and BSBY, is an unsecured rate that reflects the borrowing costs of small-to-medium sized banks across the country. Much like LIBOR, it reflects interbank borrowing on an unsecured basis, but considers actual market transactions, rather than quotes. Because it tracks unsecured borrowing between smaller banks, there is a possibility that Ameribor could be used in tandem with both SOFR and BSBY as an alternative.

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[4] Lucinda Brickler, Adam Copeland, and Antoine Martin, "Everything You Wanted to Know About the Tri-Party Repo Market, but Didn't Know to Ask", *Liberty Street Economics*, April 11, 2011.

[5] Bloomberg Professional Services, "Bloomberg Short-Term Yield Index Methodology", accessed 5 January 2022, https://assets.bbhub.io/professional/sites/10/BSBY-Methodology-Document-March-30-2021.pdf

This paper intends to add to the discussion and research surrounding these alternatives rates, primarily those that have shown significant progress towards their usage in financial markets. For this study, SOFR and the Bloomberg Short-Term Bank Yield index (BSBY) will be studied during times of illiquidity in overnight tri-party repo markets to show any aberrant behavior in said rates. Before that, this paper aims to replicate a study on BSBY, tested on other alternative reference rates, that showed rate spikes during important reporting dates for central banks, first studied by Klinger and Syrstad (2020). Lastly, this paper intends to tackle the question of a dual-benchmark solution to such behavior in markets, seeing as these rates could be countercyclical in their respective underlying markets.

## V. Literature Review

This section of the paper intends to give a brief, yet wide overview of the research being done in the field of LIBOR substitutes to show where this paper fits in to recent scholarly work. This study is by no means exhaustive, but it should give the reader an idea of how lively the area is in the realm of financial research, as well as how the paper can add to the field. For the relevant literature review, the section has been subdivided into three parts: studies concerning the relative movement of alternative rate spreads, challenges of comparing LIBOR to the suggested field of substitutes, and how practitioners intend to manage the transition from LIBOR to other alternative rates.

### *I. Key Variables in the Movement of Alternative Reference Rates*

A key motivator in the creation of this paper was a similar study by Klingler and Syrstad. The in-work examines how the alternative rates SOFR, SONIA (the Sterling Overnight Average), and ESTR (the Euro Short-Term Rate) react to certain important dates to Fixed Income markets. Crucially, the paper studies the effect of regulatory constraints, increases in treasury debt for associated countries, and changes in their corresponding central bank reserves. Their research found that regulatory constraints can either move benchmarks up or down, depending on the lender, while increases in

treasury debt increased all benchmarks and increases in central bank reserves also tended to increase benchmark rates. Although this research did not focus on the liquidity within markets behind the creation of the rates, it did focus on another topic of this paper: spikes within the rates. On these reporting dates for regulatory bodies and central banks, each benchmark rate saw a spike associated with a change in policy. This effectively means that there are events in which these rates prove to be too sensitive to use as a true benchmark rate, and where more study is needed. Because of the lack of research regarding spikes during liquidity crises, this paper can help aide the discussion of how to solve these incidents[1].

Furthermore, Klinger and Syrstad (2020) goes to show how different LIBOR and its alternatives truly are, which is a point this paper intends to address. For example, LIBOR has often been noted to have an implicit credit and liquidity premium built into the rate that's reported. This is due to quotes having these premia included by the bankers that reported their hypothetical overnight borrowing rates. However, since SOFR and other alternatives are collateralized rates, there is no way for them to include a credit risk or liquidity risk premium. This could effectively underrate what the true

[1] Sven Klingler and Olav Syrstad, "Life after Libor", *Journal of Financial Economics* Forthcoming, (October 2020).

reference rate should be, especially for long-term rates outside of daily or weekly rates[2].

*II. Challenges of Comparing LIBOR to its Alternatives*

Although the markets that are behind many of the alternatives are very liquid and have been in place for some time, contracts that use these rates are still quite new and have little liquidity in Fixed Income markets. For example, although the market mechanisms that shape SOFR (the repo and reverse-repo markets) have been in place for close to half of a century, SOFR-based contracts only started to creep into Fixed Income markets in the late 2000s. Burgess (2020) helps to support this point, showing that Alternative Reference Rate (ARR) instrument liquidity was still low in early 2019, only 2 years away from complete LIBOR transition. Because of the new market with new instruments, there is a great opportunity to learn about how they function and how they differ from LIBOR-based instruments in the past[3].

Additionally, the fundamental process of creating LIBOR greatly contrasts to the process of creating its alternatives. For example, as outlined in Schrimpf and Sushko (2019), most ARRs are specifically created through secured transactions in overnight markets. There's an inherit trade-off in

[2] Klingler and Syrstad, 4.
[3] Nicholas Burgess, "Libor Benchmark Reform: An Overview of Libor Changes and Its Impact on Yield Curves, Pricing and Risk", *University of Oxford, Saïd Business School*, (January 2020).

using overnight transactions as a rate. These reference rates will be published every day, but at the expense of having truly robust and accurate interest rates for longer-dated tenors, which this paper defines to be longer than 3-month term rates[4]. In Albanese, Iabichino, and Mammola (2021), practitioners at JP Morgan and Citigroup also note that SOFR and other alternatives have opposite cyclicalities to banks' true funding costs. During times of crisis, the rates will go to zero due to financial markets becoming less liquid as banks' funding costs soar. Because of the "flight to Treasury" that so often happens during times of financial crisis, the underlying treasuries that form the collateral in repo markets become much more valuable. This makes overnight lending in repo markets basically riskless, which means that, even though true funding costs soar during times of high risk in financial markets, overnight repo rates theoretically approach zero[5].

Burgess (2020) notes that term rates for alternatives are much less volatile than historical term rates for LIBOR. Due to the nature of alternatives being published in-arrears and their term rates being an average of the same period, there is much less movement than the published LIBOR term rates, which would often spike unexpectedly during times of crisis like the Great Financial Crisis. This is a marked difference between the two and will bring up

[4] Andreas Schrimpf and Vladyslav Sushko, "Beyond Libor: A Primer on the New Benchmark Rates", *Bank for International Settlements*, (March 2020).
[5] Claudio Albanese, Stefano Iabichino, and Paolo Mammola, "Risk Managing the Libor Transition", *Social Science Research Network*, (May 2021).

complications in this study due to there being less volatility in the rate of study[6].

From Guggenheim and Schrimpf (2020), we find that many end-users of these contracts prefer a pre-determined rate, especially small-to-medium sized corporations and retail clients. This is due to the fact that a pre-determined rate for their interest rate contracts gives cash flow management certainty that a market-based ARR simply can't do. Overall, the switch to ARRs will increase the cost of borrowing due to the uncertainty added to the ultimate rate paid. Furthermore, most IT systems and hedging instruments used by corporations, financial institutions, and retail clients alike use the cash flow certainty of pre-determined rates to determine funding costs, among other things. Due to the in-arrears calculation of most ARRs, these legacy systems must be switched to systems more compatible with in-arrears calculation[7].

Lastly, it must be noted the difference between LIBOR-based contract and derivative markets and its ARR markets. For one, as Guggenheim and Schrimpf (2020) points out, there is hardly any market for ARR-based derivatives, and the little liquidity there is in these markets would quickly dry up during crises. To have a sufficient reference benchmark, there must be

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[6] Burgess 14.
[7] Basil Guggenheim and Andreas Schrimpf, "At the Crossroads in the Transition Away from LIBOR: From Overnight to Term Rates", *Bank of International Settlements*, (October 2020).

liquidity in the markets that are underlying and trading the rate[8]. This was never a problem for LIBOR, as LIBOR-based contracts and derivatives have been traded for the past decades. LIBOR, therefore, was often referenced not only from the quoted form that banks published, but in the underlying derivatives market that implied a LIBOR rate as well. To solve this problem, the benchmarks should always reference the ARR itself and not any rate implied by ARR derivative markets until they become more liquid.

Due to these structural differences between LIBOR and its ARRs, there is a significant amount to be gained in testing how the two behave differently during different crises. Testing the key term rates of the major ARRs will prove very beneficial to understanding the key differences in LIBOR and ARR markets, and therefore, the markets trading the instruments backed by these rates.

*III. Practitioners Guide on the Transition from LIBOR*

Practitioners can give great insight into how these rates will be used going forward and their opinion on LIBOR substitutes' advantages and disadvantages. Because they're the people that will be faced with hundreds or thousands of these contracts every year, they have an incredibly large stake in understanding these rates inside-and-out. For example, Feeney (2019) argues

[8] Guggenheim and Schrimpf 12.

that using a smoothing factor during times of high volatility can help create benchmark term rates. Because many alternative benchmark rates are calculated by an average of daily, overnight rates over the term, they're much less volatile than LIBOR, which had the disadvantage of small sample sizes and biases. However, SOFR and other alternatives still show spikes in their historical back tests, leading researchers to believe that substitutes and averaging over the highly volatile period can lead to better term rates, closer to what the true reference rate should be over that period[9].

Even though Feeney (2019) uses back testing of SOFR, they're not testing the underlying causes of spikes, nor the use cases of backup benchmarks in cases of high volatility. Therefore, this paper can add to the discussion given by the Clarus Financial paper. Furthermore, Albanese, Iabichino, and Mammola (2021) proposed that, in each contract including an ARR, the lender should include a periodic funding valuation adjustment that would correct the value shift towards LIBOR. Their reasoning and tests suggest that, historically, LIBOR has followed the actual funding costs of banks, as stated previously. However, since SOFR and other ARRs are oppositely correlated with funding costs of banks, there needs to be some valuation adjustment in these new contracts that can correct towards LIBOR

[9] John Feeney, "SOFR Impacts from Liquidity Spikes", *Clarus Financial Technology*, (May 2019).

for both lending and borrowing parties[10]. The research within this paper will translate nicely to applications in practice towards these contracts, since this paper intends to correct for spikes in benchmark rates during illiquid periods. If corrections can be found through simpler means, then constantly changing funding valuation adjustments won't be necessary within the new ARR contracts.

[10] Albanese, Iabichino, and Mammola 12.

## VI. Empirical Methods and Data Review

In this section of the paper, the various methods of empirical analysis and data review will be discussed, including variables of importance, data selection, data manipulation, problems procuring data, and the methods used to find results in Econometric tests. Since the topic of ARRs are fairly new to aggregation databases, such as Bloomberg and Capital IQ, it's imperative to note the various methods of procurement, manipulation, and data series that were unable for use.

### *I. Variables of Importance in Econometric Testing*

The goal of this paper is to study volume shocks in the underlying markets in the calculation of ARRs. Therefore, the main independent variable of study is the change in overnight volume in tri-party repo transactions. The market for tri-party repo transactions plays a pivotal role in the short-term funding of financial institutions and federal agencies alike, so the volume in the underlying markets are markers for the financial health and funding needs of these institutions. A repo transaction involves the sale of an asset with the agreement to buy it back at a predetermined price, with the difference between the sale price and the repurchase price becoming the implicit interest rate of this collateralized short-term loan. A shock to this system overnight will inherently lead to imperfection in the calculation of

various ARRs that are based on these implicit rates, so the change in overnight volumes is the main variable of concern in this study.

On the other side of each regression equation is the change in the spread between the ARR of concern for each test and the Effective Federal Funds Rate. The two dependent variables of concern in these tests are the overnight rates for the Secured Overnight Financing Rate (SOFR) and the Bloomberg Short-Term Bank Yield Index (BSBY). These overnight rates reflect the overnight funding costs of international, national, and regional banks in the United States and are of primary concern in the replacement of LIBOR as a benchmark rate. Furthermore, the overnight rates are used in the calculation of term rates for longer maturity contracts, which is of great concern for longer-term financial contracts, such as variable rate mortgages and variable corporate loans and revolvers. Since the aim of this paper is to test for divergence of these rates from true funding costs during times of liquidity, these rates will be spread against the Effective Federal Funds Rate, which represents the rate at which banks can borrow from each other to meet the Federal Reserve's deposit requirements each day.

The spread between the ARR of choice and the Effective Federal Funds Rate was used for a couple of key reasons. Primarily, the EFFR represents the rate at which the Federal Reserve believes banks should be able to borrow from one another on an overnight, unsecured basis. Secondly, the researchers

Klinger and Syrstad used spreads like these in their regression studies, citing the need to benchmark the rate to central bank determined rates. Therefore, this study will use the spread to the EFFR to show "true" spikes in borrowing rates, where it should show that market-based borrowing rates are diverging from "expected" borrowing rates published by the Federal Reserve.

However, the funding costs of a bank are not at all completely determined by their activity in overnight financing markets such as the repo market. For example, greater macroeconomic trends could be occurring during these times of illiquidity and should be controlled for in any planned Econometric tests. Therefore, as a control variable, the change in the Dow Jones US Bank Index is included in all Econometric tests to control for underlying economic factors that could be affecting the funding costs of banks. This composite index tracks the performance of equities in the banking sector of the US economy, which can be seen as a proxy for overall financial health within the sector. This specific index was chosen over global or European bank indices due to its relation to American markets. Because SOFR and BSBY are mostly being considered as alternative reference rates in the US, it is more fit to use the USDJBK over global bank indices.

Another factor that must be accounted for in each Econometric test in this paper is the change in liquidity in Fixed Income derivative markets. Before its phasing out, LIBOR was derived both explicitly through quotations

and implicitly through swaps in the overnight derivative markets. Because of this, a key determinant in variable benchmarks in general is the amount of activity in swap markets that use the rate. As a control variable in Econometric tests, this paper uses the overnight changes in the SDRVOIUS index, which is tracked by Bloomberg services and records the total volume in US Dollars in Overnight Indexed Swaps markets, dating back to August 2018. This variable will control for any underlying changes in investor sentiment surrounding the alternative rates and markets that use those rates.

Finally, because this paper is modeled after a study done by Klinger and Syrstad in their paper, the Econometric tests included will control for their main variables of interest. As noted before, Klinger and Syrstad studied the effects of central bank reporting dates on the alternative rate spikes. These reporting dates included financial quarter end dates, year-end dates, and last days of each month that are not quarter-end dates. The control variables for these dates are *Quarter, Year,* and *Month/Quarter*, respectively. So, in the level-on-level tests, these indicator variables will be used to show whether the Klinger and Syrstad test holds for the BSBY Spread. For the levels-on-levels tests in this paper, the control variables from Klinger and Syrstad that will be included are the daily changes in total US Treasury Debt. In the original in-work, the researchers also use the changes in Bank Reserves at the Federal Reserve, but since this a monthly-reported series, it will not be included in

these daily change tests. Including these variables will make sure that any effects found in this paper will be independent of the significant results found in Klinger and Syrstad (2021)[1].

## *II. Data Selection, Manipulation, and Gaps within Data*

Due to the wide publication of overnight rates, finding SOFR, BSBY, and Ameribor series is relatively easy, either using the Federal Reserve databases or Bloomberg services. However, there are significant differences in how far back each series is published. For example, SOFR has only been published by the Federal Reserve as far back as 2017, leaving much of this paper's intended study out of reach. However, there are ways to find a decent proxy for the rate before this published data. In Bowman (2019), there is an equation cited that takes the General Collateralized Repo Primary Dealer survey rate and adds a factor of the difference between that survey rate and the Treasury GCF Repo Rate. The full regression equation can be found below:

$$SOFR = SurveyRate + 0.38 \cdot (GCF - SurveyRate - 0.5)$$

This equation has a remarkable $R^2$ of 99.8% in-sample, meaning that this equation is almost an exact match to the true SOFR rate before

[1] Klingler and Syrstad 5.

publication[2]. Therefore, using this regression equation, this paper extends its study back to 2014, when repo market data first started publishing on aggregation databases. Additionally, BSBY data reaches back to the start of 2016 and Ameribor to the end of 2015. Because these are lesser-known rates with more market obscurity, there are less published studies that give proxies to these rates before their official publishing. Therefore, this paper will start its study of these two alternatives at the beginning of 2016.

Repo transaction volume is also relatively easy to find due to its publishing on the Federal Reserve databases every day. The primary concern in this paper is overnight changes in volumes over a certain threshold and the volatility in the reference rate throughout the trading days after that change, so the main independent variable will be the change in overnight volumes in repo markets. Control variables of concern, including the change in the Dow Jones Bank Index, the overnight change in OIS market volumes, and the SRVIX, were also relatively simple to find and match to the variables of concern in the test, being published by Bloomberg each day.

[2] David Bowman, "Historical Proxies for the Secured Overnight Financing Rate", *FEDS Notes*, (July 2019).

*III. Econometric Methods and Testing*

To begin, this paper will first determine whether the model, laid out in the in-work by Klinger and Syrstad, holds for other ARRs. In this case, this paper will test the announcement dates of the Federal Reserve on the BSBY Spread to determine whether the results from the 2021 in-work holds for the BSBY. For this test, the model will be of the form:

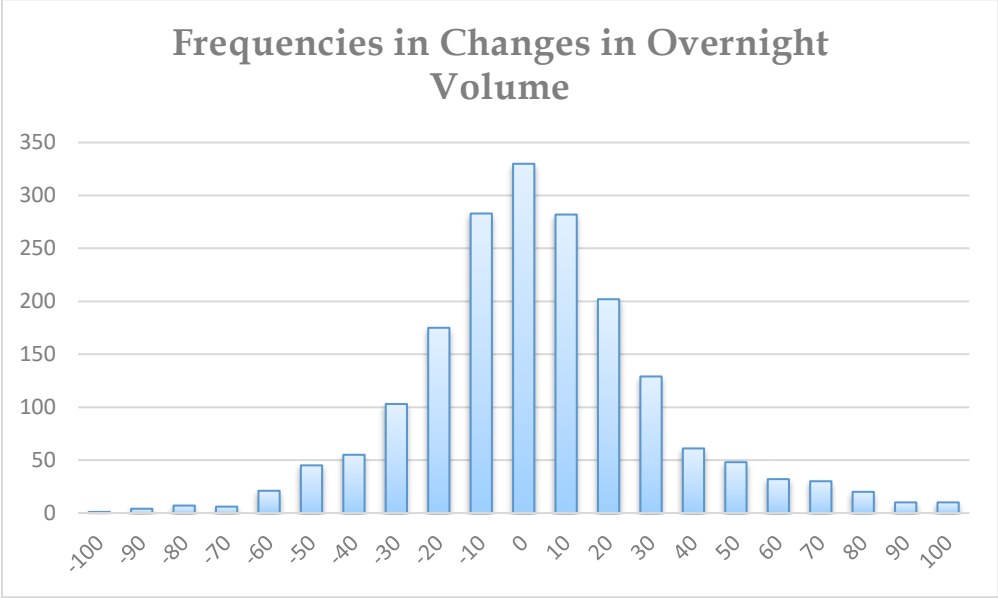
$$(BSBY - EFFR) = \beta_0 + \beta_1*(Quarter) + \beta_2*(Year) + \beta_3*(Month \setminus Quarter)$$

This model, with three indicator variables, will determine whether the BSBY has a tendency to spike during reporting dates of the Federal Reserve, much like Klinger and Syrstad did in their 2021 study for SOFR, ESTR, and SONIA.

The main concern in any levels-on-levels tests run and any methodology is the difference in relationship between alternative rates and liquidity during "normal" market conditions and illiquid market conditions. Therefore, the majority of testing will contrast the relationship during normal market conditions and illiquid market conditions. A dummy variable, informally noted as "2 Sigma Dummy", will help to distinguish these two conditions. The two-sigma dummy variable denotes decreases in overnight volumes that surpass two standard deviations in negative overnight volume changes in tri-party repo transactions and the two days of trading following that event. To contribute to the use of a normal distribution in tracking these abnormal and

negative volume events, the plot of frequencies in changes in overnight volume can be found below, indicating an approximation of the normal distribution.

*Exhibit 1: Histogram of Changes in Overnight Volume*




The planned Econometric tests involve both a levels-on-levels and difference-in-difference distinction within the tests. This paper hopes to study the effects of a *change* in overnight repo volumes, among other changes in control variables, on the *change* in the respective ARR spreads. Therefore, it is distinguished as a levels-on-levels test, rather than testing the level of each variable on the level of the spread at a certain point. Furthermore, since the planned tests involve a normal set of variables with no interaction and the interacted set of variables to show changes to the relationships in times of

illiquidity, these tests are also difference-in-difference tests. One could think of the uninteracted variables in each test as a "control" sample and the variables interacted with the illiquidity indicator variable as the "treatment" sample. The analysis will then happen in the difference in relationship between the control sample variables and the treatment sample variables.

Given the definitions above, the first planned econometric levels-on-levels test for each spread variable is of the form:

$$\Delta EFFR\ Spread = \beta_0 + \beta_1 * (\Delta\ Overnight\ Volumes) + \beta_2 * (\Delta\ Bank\ Index) + \beta_3 * (\Delta\ SDRVOIUS) + \beta_4 * (\Delta\ Total\ Treasury\ Debt) + \beta_5 * (\Delta\ Overnight\ Volumes * 2sigma) + \beta_6 * (\Delta\ Bank\ Index * 2sigma) + \beta_7 * (\Delta\ SDRVOIUS * 2sigma) + \beta_8 * (\Delta\ Total\ Treasury\ Debt * 2sigma)$$

The value of examination will come in testing the incremental difference between $\beta_1$ and $\beta_6$, since that is the primary goal of this paper. Any differences in other parameters will be noted, but not deeply examined since they are not a subject of this study.

Secondly, because volatility plays a key role in the study of interest rate movements, the second set of regressions will interact certain kinds of volatility with the variables included in the above regressions. These included variables will increase the importance of explanatory variables during times of high volatility in underlying market volumes, which will hypothetically increase the effectiveness of tests run. The volatility chosen for this study is

the SRVIX, which is the CBOE Interest Rate Volatility Index, which captures volatility surrounding all interest rates and interest rate derivative contracts.

Lastly, due to the second study that the paper hopes to accomplish, the empirical section will include regressions of EFFR Spreads between benchmark rates. This will hopefully show any countercyclicality between rates for a two-benchmark solution in the future. The planned econometric tests are shown below.

$$EFFR\ Spread_i = \beta_1 * EFFR\ Spread_j + u_i$$

*IV. Testable Hypotheses*

Using the analyses above and the research done before, especially in light of Klingler and Syrstad (2020), this paper posits that (1) the findings in Klingler and Syrstad (2020) with significance in reporting dates will hold for the BSBY rate as well, (2) decreases in overnight volume in underlying tri-party repo markets larger than two standard deviations will have a statistically significant and negative impacts on their respective reference rate spreads to the Effective Federal Funds Rate, resulting in a "spike" of the rate, and that (3) the SOFR and BSBY rates will prove to be positively and highly correlated with each other, but Ameribor will prove to be positively correlated to a much smaller magnitude, indicating evidence that a dual

benchmark solution could work for interest rate contracts using Ameribor as a secondary rate.

## VII. Empirical Analysis and Results

This section of the paper intends to review summary statistics of key variables, discuss results of Econometric tests that were run, and contextualize results with hypotheses previously stated and previous research cited in the paper.

### *I. Summary Statistics of Key Variables*

With the first test, this paper will show if the Klinger-Syrstad model will hold for the BSBY Spread. The variables of importance are the Quarter-End indicator variable, the Year-End indicator variable, and the Month-End indicator variable. The summary statistics for stated variables are below.

*Exhibit 2: Summary Statistics for BSBY Spread Test on K-S Model*

| **Variables in Replication of K-S Tests** | **Observations** | **Mean** | **Standard Deviation** | **Minimum** | **Max** |
|---|---|---|---|---|---|
| *BSBY Spread (Basis Points)* | 1534 | -0.2145 | 16.56 | -61.00 | 179.00 |
| *Quarter-End Indicator Variable* | 1532 | 0.0157 | 0.12 | -100.00 | 123.00 |
| *Year-End Indicator Variable* | 1532 | 0.0039 | 0.06 | -270.00 | 282.00 |
| *Month-End \ Quarter-End Indicator Variable* | 1532 | 0.0320 | 0.18 | -55.63 | 46.71 |

We mostly notice here how many "1" observations each of the indicator variables have: Quarter with 24, Year with 6, and Month\Quarter with 49. Furthermore, the Spread has an average of -0.21 basis points with a wide range, indicating that there is a lot of variation to explain and test on.

With the first of the levels-on-levels tests planned, the main variables of concern are the overnight changes in the Spread between SOFR and the Effective Federal Funds Rate, Changes in Overnight Volume, both in conditions of normality and illiquidity, the Changes in Dow Jones Bank Index, and the Changes in Total Volume in Overnight Index Swap Markets. Because the volume metrics for both overnight repo market volume and OIS market volume are so large, the summary statistics for those measures will be presented in Billions of USD and Thousands of USD, respectively. Furthermore, the Spread statistics are denoted in basis points. Below are the summary statistics for those key variables.

*Exhibit 3: Summary Statistics for First Planned Econometric Test on SOFR Spread*

| **Variables in First SOFR Tests** | **Observations** | **Mean** | **Standard Deviation** | **Minimum** | **Max** |
|---|---|---|---|---|---|
| *Changes in O/N Volume in Normality (Billions of $)* | 1770 | 1.2900 | 29.93 | -61.00 | 179.00 |
| *Change in O/N Volume In Illiquidity (Billions of $)* | 102 | -19.3400 | 51.49 | -100.00 | 123.00 |
| *Change in Spread (Basis Points)* | 1872 | 0.0004 | 11.02 | -270.00 | 282.00 |
| *Change in US Dow Jones Bank Index* | 1872 | -0.1660 | 6.82 | -55.63 | 46.71 |
| *Change in Total Volume in OIS Markets (Thousands of $)* | 1872 | 0.3254 | 60.36 | -362.40 | 502.12 |
| *Change in Total Treasury Debt (Billions of $)* | 1872 | 6.5654 | 29.07 | -86.58 | 339.11 |

In Exhibit 3, we notice that there are 102 days of trading in the observation set for days of illiquidity. Of course, since the study includes the two days after the 2-sigma event occurs, the maximum is going to include

some outliers where the volume bounces back within the market. That is exactly the case here, with the maximum overnight repo volume being at 123 in that set of observations. An interesting point to note is that the changes in overnight volume in normality has a mean close to zero with 1.29, indicating that the distribution of overnight changes in volume is close to a normal distribution around zero, as noted earlier in the paper. The inclusion of the daily changes in treasury debt is to control for the variables from the Klingler and Syrstad in-work as much as possible, seeing as their levels-on-levels test included this change variable. One final note from these statistics is that the change in overnight volume during times of illiquidity has a much higher standard deviation than the normality overnight volume, indicating that there's much volatility to be studied.

The second set of summary statistics will be similar in form to the first, but will create the summary statistics for the Change in the BSBY Spread and its related change in volume. The summary statistics are shown below:

*Exhibit 4: Summary Statistics for First Planned Econometric Test on BSBY Spread*

| Variables in First BSBY Test | Observations | Mean | Standard Deviation | Minimum | Max |
|---|---|---|---|---|---|
| *Changes in O/N Volume in Normality (Billions of $)* | 1456 | 1.260 | 30.58 | -64.00 | 179.00 |
| *Change in O/N Volume In Illiquidity* | 78 | -19.320 | 52.97 | -100.00 | 123.00 |
| *Change in Spread (Basis Points)* | 1533 | -0.014 | 4.31 | -30.25 | 84.60 |
| *Change in US Dow Jones Bank Index* | 1531 | 0.156 | 7.32 | -55.63 | 46.71 |
| *Change in Total Volume in OIS Markets (Thousands of $)* | 1531 | 114.600 | 87.71 | -362.40 | 502.12 |
| *Change in Total Treasury Debt (Billions of $)* | 1532 | 7.231 | 30.25 | -86.58 | 317.59 |

For the BSBY tests that are planned, there is a slightly smaller observation size, since BSBY data only reaches back to 2016. Therefore, in the illiquidity side of the test, there are only 78 obsrvations of negative two-sigma events in the overnight markets, which should still be a sizeable enough sample size to run the necessary tests. Like the SOFR observation set, there are bound to be outliers in the minimum and maximums of each variable because we are working with such a large group of observations. However, in the Change in Spread summary statistics, we see that the mean is close to zero, with large outliers on either side, showing that there is much volatility to be studied.

For the second round of planned tests, this paper will study the effects that volatility within the broader interest rate market has on these regressions. In order to do so, each explanatory variable in the regressions

above will be interacted with the CBOE Interest Rate Volatility Index, labeled SRVIX in this dataset. This will theoretically give more importance to explanatory variables during times of high volatility within interest rates, while minimizing their importance during times of low volatility. The SRVIX has been scaled to its mean over the time period so that we can draw meaningful conclusions in individual statistics within SRVIX, such as the standard deviation, minimum, and maximum. For example, an observation of 1.20 in the Scaled SRVIX variable means that, on this specific day, interest rates were 20% more volatile in forward looking swap rates than the average over the period. Below are the summary statistics in this second round of tests, given the interacted variables in the leftmost column:

*Exhibit 5: Summary Statistics for Second Planned Econometric Test on SOFR Spread*

| **Variables in Second SOFR Tests** | **Observations** | **Mean** | **Standard Deviation** | **Minimum** | **Max** |
|---|---|---|---|---|---|
| *Change in Volume in Normality x SRVIX (Billions of $)* | 1764 | 1.180 | 28.69 | -67.48 | 151.47 |
| *Change in Volume in Illiquidity x SRVIX* | 102 | -17.790 | 49.45 | -94.28 | 137.54 |
| *Change in Bank Index x SRVIX* | 1867 | 0.132 | 6.52 | -46.87 | 39.60 |
| *Change in OIS Volume x SRVIX (Thousands of $)* | 1867 | 0.004 | 59.59 | -423.47 | 312.51 |
| *Change in Total Treasury Debt x SRVIX (Billions of $)* | 1867 | 6.290 | 28.49 | -73.70 | 381.44 |
| *Scaled SRVIX* | 1867 | 1.000 | 0.11 | 0.78 | 1.31 |

These results for some variables are quite surprising, while others are not so surprising. For example, both the mean and the standard deviation of changes in overnight volume in both illiquid and normal periods shift towards zero, indicating that there is a negative correlation between the forward-looking volatility of interest rates and the changes in overnight repo market volume. That is, when there are large changes in overnight volume, they are countered by low forward-looking volatilities, and vice versa with small changes in overnight volume. This is deeply surprising, given that you'd expect large changes in markets that determine interest rates to lead to large changes in those interest rates, which would lead to higher implied volatility. That is not the case here. Furthermore, there's very little change in other explanatory variables, except for a shrinking in the mean in both the change in bank index and the change in volume in OIS markets. Finally, as expected, the mean of scaled SRVIX is 1 (because it was forced towards 1), while the standard deviation is around 11%, meaning there is good variation within this interacted series to study.

*Exhibit 6: Summary Statistics for the Second Planned Econometric Test on BSBY Spread*

| Variables in Second BSBY Test | Observations | Mean | Standard Deviation | Minimum | Max |
|---|---|---|---|---|---|
| *Change in Volume in Normality x SRVIX (Billions of $)* | 1448 | 1.180 | 30.19 | -74.61 | 155.00 |
| *Change in Volume in Illiquidity x SRVIX (Billions of $)* | 78 | -18.160 | 50.94 | -97.10 | 141.65 |
| *Change in Bank Index x SRVIX* | 1526 | 0.143 | 7.12 | -48.27 | 40.78 |
| *Change in OIS Volume x SRVIX (Thousands of $)* | 1526 | -0.002 | 92.53 | -436.12 | 321.85 |
| *Change in Total Treasury Debt x SRVIX (Billions of $)* | 1526 | 7.015 | 29.98 | -75.90 | 333.60 |
| *Scaled SRVIX* | 1526 | 1.000 | 0.11 | 0.80 | 1.35 |

Similar to the summary statistics from the second SOFR spread test, the means and standard deviation for both change in volume variables have shrunk towards zero, indicating negative correlations with forward looking interest rate volatilities. One interesting note here is that the interacted change in OIS Volume variable shows much more volatility in this set of observations in comparison to the SOFR observations, as shown by a much higher standard deviation. One potential explanation is that the overnight changes in OIS Volumes have become much larger over time as the market has increased in participants, thereby having larger fluctuations in transactions as time has gone on.

The final planned test of this study are correlative studies of each spread to find if there exists any countercyclicalities in the rates. The combined summary statistics can be found below:

*Exhibit 7: Summary Statistics for Planned Spread Cyclicality Econometric Test*

| Variables in Correlative Spread Test | Observations | Mean | Standard Deviation | Minimum | Max |
|---|---|---|---|---|---|
| *SOFR Spread (SOFR - EFFR)* | 1532 | -0.002 | 0.17 | -1.49 | 0.37 |
| *BSBY Spread (BSBY - EFFR)* | 1532 | -0.029 | 0.21 | -1.58 | 3.21 |
| *Ameribor Spread (Ameribor - EFFR)* | 1532 | 0.084 | 0.21 | -1.42 | 0.49 |

When compared side-by-side, there is not much difference between the SOFR and BSBY spreads, other than their maximum values (due to a blip in SOFR calculation in September 2019). However, there is a marked difference in the summary statistics of the two rates and Ameribor. For one, the mean spread over the period is positive and close to four times larger than the SOFR spread. This is due to the fact that Ameribor is primarily an unsecured rate, which means there is an inherent credit spread imbued in the rate. This pushes the average up, while keeping the standard deviation in line with the other two spreads. It is interesting to note, however, that the minimum of the Ameribor spread is pretty close to that of the BSBY and SOFR spreads. In any case, this data is promising that there is some countercyclicality between Ameribor and the two similar spreads.

## *II. Results of Econometric Tests*

This section will discuss the various results of the planned econometric tests that have been mentioned above. One asterisk above variable names in exhibits indicates significance at the 90% confidence level, two asterisks above variable names indicates significance at the 95% confidence level, and three

asterisks above variable names indicates significance at the 99% confidence level.

*a) BSBY Spread Tests on K-S Model*

*Exhibit 8: BSBY Spread Level Econometric Test on K-S Model*

| **BSBY Spread** | **Coeff.** | **t-statistics** |
|---|---|---|
| *Quarter-End* | -3.21227 | -0.78 |
| | *3.92838* | |
| *Year-End** | 14.83500 | 1.90 |
| | *7.80873* | |
| *Month-End \ Quarter-End* | -0.46596 | -0.19 |
| | *2.40581* | |
| *Constant* | -0.20657 | -0.48 |
| | *0.43367* | |
| *R^2* | *0.24%* | |

Interestingly enough, the results from Klinger and Syrstad do not apply to the BSBY Spread as well as they did to the SOFR Spread, among other ARRs in that test such as ESTR and SONIA. The Quarter-End and Month-End variables are not statistically significant with the BSBY rate, with the Year-End variable only being statistically significant above the 90% confidence level. One explanation for the lack of explanatory power from the date indicator variables is that the securities that are traded within the BSBY markets are not directly affected by Federal Reserve announcement dates. SOFR and other ARRs are made up of repo transactions, most of which use treasuries as collateral. Since the markets underlying the BSBY Index are

mostly made up of Commercial Paper and Certificate of Deposit trades, announcement dates would affect the calculation of the rate less than SOFR. Therefore, this result makes a little sense, but it is still unfortunate that we can not use the same research as Klinger and Syrstad and apply it to the BSBY Index.

*b) SOFR Spread Econometric Tests*

*Exhibit 7: SOFR Econometric Test and Coefficients under Normal Conditions*

| **SOFR Spread in Normality** | **Coeff.** | **t-statistics** |
|---|---|---|
| *Change in O/N Volume (Billions of $) **** | 0.04000<br>*0.00861* | 4.65 |
| *Change in Dow Jones US Bank Index* | -0.00650<br>*0.03761* | -0.17 |
| *Change in Total Volume in OIS Markets (Thousands of $)* | -0.00078<br>*0.00414* | -0.19 |
| *Change in Spread L1 **** | -0.28593<br>*0.02235* | -12.79 |
| *Change in Total Treasury Debt (Billions of $)* | 0.00537<br>*0.00862* | 0.62 |
| *Constant* | -0.09575<br>*0.25133* | -0.38 |
| *R^2* | *8.78%* | |

*Exhibit 8: SOFR Spread Econometric Test and Coefficients under Illiquidity*

| SOFR Spread In Illiqudity | Coeff. | t-statistics |
|---|---|---|
| *Change in O/N Volume (Billions of $) ** | -0.04751<br>*0.02117* | -2.24 |
| *Change in Dow Jones US Bank Index* | 0.02990<br>*0.12401* | 0.24 |
| *Change in Total Volume in OIS Markets (Thousands of $)* | 0.01130<br>*0.02013* | 0.56 |
| *Change in Spread L1* | 0.17758<br>*0.22880* | 0.78 |
| *Change in Total Treasury Debt (Billions of $)* | -0.00383<br>*0.03749* | -0.10 |
| *R^2* | *8.78%* | |

Here we see the results of the first Econometric test run for the levels-on-levels analysis. The variables in Exhibit 7 are the variable of interest and the control variables that have not been interacted with the 2-sigma dummy variable. In Exhibit 8, the variables included have been interacted with the 2-sigma dummy variable. Therefore, the coefficients and statistics in the second table represent a change in the relationship between these variables and the change in spread during times of illiquidity. The main variable of concern, the change in overnight volumes, shows a significant difference in relationship during times of illiquidity than in normality. Above a 95% confidence level, this test shows that the relationship inverts during severe drops in overnight volumes, so that the change in the SOFR Spread will be positive and

significant. Other than that, the other explanatory variables, such as the change in the bank index, change in volume in OIS Markets, and the lagged change in SOFR spread are all statistically insignificant and close to zero in their effect on the change in SOFR Spread. On another note, the addition of these variables shows that the Klinger and Syrstad variables included, the daily change in total treasury debt, becomes insignificant when taking into account change in the bank index, change in the volume in OIS markets, and the lagged change variable.

These first results indicate that the initial hypothesis was correct. Given a negative and statistically significant coefficient on the change in volume term in Exhibit 8, we can see that a negative shock to overnight volume during times of illiquidity will cause a spike in the SOFR spread to the EFFR. However, promising as these results may be, the $R^2$ on this initial Econometric test is a lowly $R^2$ of 8.78%, indicating that more variation could be explained by these variables.

Even with good preliminary results to show that there is a marked difference in the relationship between the SOFR Spread and the change in overnight repo volume in times of illiquidity, the F-test to determine difference between the two coefficients is shown in the appendix as Exhibit 19[1]. With a probability of 0.07% that the two change in repo transaction

[1] See Page 54

volume variables are actually redundant within this test, this shows that there is an important difference between the two variables with confidence.

The final planned tests for the change in the SOFR Spread include an interaction with the Interest Rate Volatility Index, noted as SRVIX in this paper. The inclusion of this interaction on explanatory variables will hopefully produce more importance during times of high volatility in interest rates, while decreasing importance of explanatory variables during times of low volatility. The importance of this interaction is to show what happens to the explanatory variables when the national and regional bank's funding costs are in flux, which is represented by increasing volatility in forward-looking interest rates. The results of the regression with the interacted variables can be found below.

*Exhibit 9: SOFR Spread Test and Coefficients (Normal Conditions) with Volatility Interaction*

| SOFR Spread In Normality | Coeff. | t-statistics | Variables | Coeff. | t-statistics |
|---|---|---|---|---|---|
| *Change in Volume X SRVIX* | -0.0570 | -0.72 | *Change in O/N Volume (Billions of $)* | 0.0963 | 1.24 |
| | *0.0792* | | | *0.0777* | |
| *Change in DJUSBK X SRVIX* | -0.0863 | -0.27 | *Change in Dow Jones US Bank Index* | 0.0766 | 0.25 |
| | *0.3179* | | | *0.3056* | |
| *Change in TVOIS X SRVIX* | 0.0508 | 1.22 | *Change in Total Volume in OIS Markets (Thousands of $)* | -0.0520 | -1.24 |
| | *0.0415* | | | *0.0420* | |
| *Change in Spread L1 X SRVIX* | 0.1053 | 0.26 | *Change in Spread L1* | -0.3865 | -0.99 |
| | *0.4084* | | | *0.3898* | |
| *Change in Treasury Debt X SRVIX* | -0.0403 | -0.49 | *Change in Treasury Debt* | 0.0447 | 0.55 |
| | *0.0823* | | | *0.0812* | |
| *SRVIX* | -0.4572 | -0.21 | | | |
| | *2.1801* | | | | |
| *Constant* | 0.3864 | 0.18 | | | |
| | *2.1964* | | | | |
| *R^2* | *8.97%* | | | | |

*Exhibit 10: SOFR Spread Test and Coefficients (Illiquid Conditions) with Interacted Volatility*

| SOFR Spread In Illiqudity | Coeff. | t-statistics | Variables | Coeff. | t-statistics |
|---|---|---|---|---|---|
| *Volume X SRVIX* | 0.1966 | 0.96 | *Change in O/N Volume (Billions of $)* | -0.2357 | -1.20 |
| | *0.2045* | | | *0.1963* | |
| *DJUSBK X SRVIX* | 0.4514 | 0.28 | *Change in Dow Jones US Bank Index* | -0.3799 | -0.26 |
| | *1.6060* | | | *1.4392* | |
| *TVOIS X SRVIX* | 0.0799 | 0.37 | *Change in Total Volume in OIS Markets (Thousands of $)* | -0.0626 | -0.30 |
| | *0.2153* | | | *0.2075* | |
| *Spread L1 X SRVIX* | -2.3494 | -0.5 | *Change in Spread L1* | 2.3634 | 0.54 |
| | *4.7090* | | | *4.3683* | |
| *Change in Treasury Debt X SRVIX* | 0.0217 | 0.04 | *Change in Treasury Debt* | -0.0313 | -0.06 |
| | *0.6062* | | | *0.5462* | |
| *R^2* | *8.97%* | | | | |

In comparison to the first regressions run on the SOFR Spread, much has changed in terms of importance and statistical significance between the explanatory variables. For example, the interaction variable for overnight changes in repo transactions has a positive, but insignificant coefficient. This relationship points in the opposite direction of the relationship established in

the first test run in this section. Therefore, we can see that the interaction of continuous volatility actually diminishes the importance of the independent variables in their explanatory power on the change in SOFR Spread. Furthermore, no explanatory variables have statistically significant coefficients above a 90% confidence level, meaning that the interaction has severely diminished the actual explanatory power of these variables. The regression $R^2$ is 8.97%, showing that not much more variation is explained by the inclusion of the interacted variables.

Because this last regression is very similar to the first regression, despite the lowering of significance for the explanatory variables, we can expect similar results in the F-test to show difference in the coefficients. Here, the probability that the two coefficients are different is 0.5%, giving us more than 99% confidence that the relationship between the overnight changes in volume in repo markets and the change in the SOFR Spread is different during times of illiquidity in those markets than in times of normality. However, since the coefficients are not significant on their own, not much importance in difference can be gleaned from the results of this F-test.

*c) BSBY Econometric Tests*

To establish consistency between the tests of the change in SOFR Spread and the change in BSBY Spread, the planned Econometric tests are exactly

similar to those in the previous section. However, there will be comparisons drawn due to their similarity in chapters to come, noting the difference in relationships between the two spreads and their respective volumes. The first regressions run for the BSBY Spread are shown below without the volatility interactions.

*Exhibit 11: BSBY Econometric Test and Coefficients under Normal Conditions*

| **BSBY Spread In Normality** | **Coeff.** | **t-statistics** |
|---|---|---|
| *Change in O/N Volume (Billions of $)* | 0.005072<br>*0.003660* | 1.39 |
| *Change in Dow Jones US Bank Index* | -0.00337<br>*0.01544* | -0.22 |
| *Change in Total Volume in OIS Markets (Thousands of $)* | -0.00115<br>*0.00171* | -0.67 |
| *Change in Spread L1* | -0.01762<br>*0.02672* | -0.66 |
| *Change in Total Treasury Debt (Billions of $)* | 0.005762<br>*0.00369* | 1.56 |
| *Constant* | -0.05542<br>*0.11243* | -0.49 |
| *R^2* | *2.97%* | |

*Exhibit 12: BSBY Econometric Test and Coefficients under Illiquid Conditions*

| **BSBY Spread In Illiqudity** | **Coeff.** | **t-statistics** |
|---|---|---|
| *Change in O/N Volume (Billions of $) ** | -0.016476<br>*0.0095245* | -1.73 |
| *Change in Dow Jones US Bank Index* | 0.0336625<br>*0.0593873* | 0.57 |
| *Change in Total Volume in OIS Markets (Thousands of $)* | 0.006633<br>*0.0099545* | 0.67 |
| *Change in Total Treasury Debt (Billions of $)* | -0.002849<br>*0.0172357* | -0.17 |
| *Change in Spread L1**** | 0.5063543<br>*0.0864389* | 5.86 |
| *R^2* | *2.97%* | |

Here, we see that there is no statistical significance to the relationship between the change in overnight volumes and the change in the BSBY Spread during times of normality, but that changes to a statistically significant and negative relationship during times of illiquidity in the market at a 90% confidence level. Furthermore, both the USDJBK Index and the OIS market volumes are not significant in both times of normality and illiquidity. Furthermore, like the change in the SOFR Spread tests above, the daily change in total treasury debt is neither explanatory during normality nor illiquidity in the repo markets, although it is slightly significant during normality. The only explanatory variables that show high significance in these tests are the lagged change in spread variables, indicating that the BSBY Spread has some friction associated with it. As for explaining variation in the

spread, the changes in volumes here do a much worse job than that of the first tests, producing an $R^2$ of 2.97%.

Looking towards Exhibit 21 in the Appendix[2], we notice that the F-test between normality and illiquidity results in a confidence level of 94% that the relationship changes during times of illiquidity. This is a great sign for the first hypothesis, given that there is a significantly different relationship between times of illiquidity and times of normality for the changes in the BSBY Spread.

Lastly, like before, the interaction of the SRVIX with the explanatory variables will prove key to drawing out importance during times of high volatility (i.e., when bank's funding costs rise), and minimizing their importance when volatility in interest rates is low. The results of the regression are shown below.

*Exhibit 13: BSBY Spread Test and Coefficients (Normal Conditions) with Volatility Interaction*

[2] See Page 54

| BSBY Spread In Normality | Coeff. | t-statistics | Variables | Coeff. | t-statistics |
|---|---|---|---|---|---|
| *Change in Volume X SRVIX* | -0.0190 | -0.53 | *Change in O/N Volume* | 0.0235 | 0.67 |
| | *0.0357* | | *(Billions of $)* | *0.0352* | |
| *Change in DJUSBK X SRVIX* | 0.0729 | 0.55 | *Change in Dow Jones US Bank Index* | -0.0729 | -0.56 |
| | *0.1334* | | | *0.1300* | |
| *Change in TVOIS X SRVIX* | 0.0183 | 1.09 | *Change in Total Volume in OIS* | -0.0200 | -1.14 |
| | *0.0169* | | *Markets (Thousands of $)* | *0.0175* | |
| *Change in Spread L1 X SRVIX*** | -0.7137 | -2.31 | *Change in Spread L1*** | 0.6924 | 2.24 |
| | *0.3092* | | | *0.3090* | |
| *Change in Treasury Debt X SRVIX* | 0.0008 | 0.02 | *Change in Treasury Debt* | 0.0046 | 0.13 |
| | *0.0362* | | | *0.0360* | |
| *SRVIX* | -0.6022 | -0.57 | | | |
| | *1.0523* | | | | |
| *Constant* | 0.6754 | 0.65 | | | |
| | *1.0325* | | | | |
| *R^2* | *4.16%* | | | | |

*Exhibit 14: BSBY Spread Test and Coefficients (Illiquid Condition) with Volatility Interaction*

| BSBY Spread In Illiqudity | Coeff. | t-statistics | Variables | Coeff. | t-statistics |
|---|---|---|---|---|---|
| *Volume X SRVIX* | -0.0564 | -0.47 | *Change in O/N Volume* | 0.0354 | 0.31 |
| | *0.1193* | | *(Billions of $)* | *0.1144* | |
| *DJUSBK X SRVIX* | 0.1528 | 0.16 | *Change in Dow Jones US Bank Index* | -0.0784 | -0.10 |
| | *0.8541* | | | *0.8001* | |
| *TVOIS X SRVIX* | -0.2654 | -1.10 | *Change in Total Volume in OIS* | 0.2594 | 1.13 |
| | *0.2409* | | *Markets (Thousands of $)* | *0.2298* | |
| *Change in Treasury Debt X SRVIX* | -0.0380 | -0.12 | *Change in Treasury Debt* | 0.0386 | 0.13 |
| | *0.3065* | | | *0.2885* | |
| *Spread L1 X SRVIX**** | 11.9387 | 3.46 | *Change in Spread L1**** | -10.9897 | -3.31 |
| | *3.4527* | | | *3.3198* | |
| *R^2* | *4.16%* | | | | |

Given the regression run with the interacted variables, there are a couple interesting things to note. Like before with the SOFR Spread, all variables have lost a decent amount of significance with the inclusion of the

volatility-interacted terms. This is to be expected because the inclusion of any terms will most likely weaken the explanatory power of individual variables. However, there are now no statistically significant variables to high degrees of confidence. Furthermore, many of the interacted terms point in opposite directions to their regular counterparts, such as the overnight change in volumes in illiquidity and in normality. This probably means that the interacted terms are redundantly included. Lastly, the inclusion of interacted terms increases the explanatory power of the test by about 1.5 percentage points compared to the first regression, giving this test an $R^2$ of 4.16%.

However, even though the two coefficients on the change in volumes are not statistically significant on their own, there is still some proof that there's a difference between the two relationships as it relates to the change in the BSBY Spread. The F-Test, shown in Exhibit 22 in the Appendix[3], gives a probability of 4.78% that the two variables inclusion are redundant in this test, meaning that there is still a significant difference in the relationship between overnight changes in volume and the change in the BSBY Spread during times of normality and illiquidity.

[3] See Page 54

*d) Dual Benchmark Tests*

The final part of this Econometric study plans to test for low correlations and close to zero relationships between spread variables. The hope is that, if a pair of these spread variables have a low correlation and no causal relationship between each other, then they can be used in conjunction in interest rate contracts. In other words, when one rate becomes untethered from the EFFR and true funding costs, another can take its place and serve as the reference rate for a period of time. Like stated before, the hypothesis within this section is that Ameribor, as an unsecured rate dealing with the funding costs of regional banks, will have a low correlation with the other two rates and will have little causal relationship between the drivers of said rates.

The first part of this study involves a correlation matrix between spread variables. The results of the study are found below.

*Exhibit 15: Spread Correlation Matrix*

| **EFFR Spread Correlation Matrix** | | | |
|---|---|---|---|
| | *BSBY* | *SOFR* | *Ameribor* |
| *BSBY* | 1.000 | | |
| *SOFR* | 0.787 | 1.000 | |
| *Ameribor* | 0.908 | 0.805 | 1.000 |

Contrary to the stated hypothesis, all three spreads have high correlations with one another, with Ameribor having the highest correlations with the two spreads in question. This result, although disappointing in terms of the hypothesis, is to be expected, since the drivers of all three rates and respective spreads to the EFFR are similar: the funding costs of banks. The regional, national, or international identities of said banks seems to be less important than initially theorized. However, there is still some space to show that there is no causal link between the drivers of the spreads, which will be shown through a trio of regressions between the three spreads in question.

*Exhibit 16: SOFR Spread Regressed on BSBY Spread*

| **SOFR Spread** | **Coeff.** | **t-statistics** |
|---|---|---|
| *BSBY Spread**** | 1.00916 | 29.92 |
| | *0.020217* | |
| *Constant**** | -0.02641 | -7.89 |
| | *0.00335* | |

*Exhibit 17: SOFR Spread Regressed on Ameribor Spread*

| **SOFR Spread** | **Coeff.** | **t-statistics** |
|---|---|---|
| *Ameribor Spread**** | 0.83027 | 53.14 |
| | *0.015625* | |
| *Constant**** | -0.09815 | -28.25 |
| | *0.00347* | |

*Exhibit 18: BSBY Spread Regressed on Ameribor Spread*

| BSBY Spread | Coeff. | t-statistics |
|---|---|---|
| *Ameribor Spread**** | 0.730305 | 84.88 |
| | *0.008604* | |
| *Constant**** | -0.06334 | -33.11 |
| | *0.00191* | |

It's clear to see, given these three tests, that all three rate spreads have relationships between the drivers of the rates. This was assumed between SOFR and BSBY, given that they're more national rates, derived by the activity of larger rates, but it's interesting to note that the lowest amount of variation is explained in the regressions without Ameribor, when it was hypothesized that the lowest t-statistics and $R^2$ values would come in the other two regressions. In any case, these tests and the correlation matrix ultimately disprove the hypothesis that there are smaller correlations between SOFR/BSBY and Ameribor.

### *III. Contextualization of Results*

The regression results found above can be deceiving in terms of their magnitude, given how small the coefficients are and the large scale of the independent variables. For example, in the first regression on the change in the SOFR Spread, the variable of interest, the overnight change in repo market volume during illiquid markets, has a statistically significant coefficient of -0.0475112 and a standard error of 0.0211719. In real terms, the

change in the SOFR Spread is stated in basis points, while the overnight volume variables are expressed in billions of USD. Given those data definitions, a $100 Billion dollar decrease in overnight repo market activity will move the SOFR Spread to the EFFR by about 4.75 basis points, controlling for other market variables. That's still incredibly small on its own!

The economic importance should not be lost in the magnitude of these results, however. During its peak usage, there were an estimated $200 Trillion in interest rate contracts that referenced USD LIBOR as its main reference rate[4]. Given that SOFR is the pick from the ARCC and Federal Reserve to be the new reference rate on variable rate contracts, it's no overstatement that the amount in SOFR contracts going forward will exceed that of the USD LIBOR contracts in the past. With that said, even a one basis point movement in the spread to the EFFR overnight will have major implications to the value of these contracts. A sustained period of illiquidity following these market shocks would be devastating for the lenders of variable rate debt.

Similar effects are found within the BSBY Spread regressions, where a negative overnight change in $100 Billion of volume moves the BSBY Spread by around 1.5 basis points. However, there are much less projected contracts that will be using BSBY as a reference rate than SOFR. The "stamp of

[4] The Alternative Reference Rates Committee, "Progress Report: The Transition from U.S. Dollar LIBOR", NewYorkFed.org, The New York Federal Reserve Bank, March 31, 2021.

approval" by the ARCC and the Federal Reserve means that the relationship between volume shocks in overnight repo markets are much more economically important to SOFR-based contracts than to BSBY-based contracts. There isn't a good estimate as to how many lenders and practitioners will be using BSBY as a reference rate going forward, but the sentiment in Fixed Income markets as of today shows a favoring of SOFR over other rates.

Finally, the correlational testing between the interest rate spreads served to disprove the third hypothesis. Given the high correlations between the rates and the similarity between the drivers of said rates, it would be unwise and, frankly, a waste of time to pair any of three in a "dual benchmark" contract or index. Even so, there still could be a market-determined interest rate that show little correlation to the three mentioned above. Further studies into a dual benchmark solution could prove very useful in determining solutions to market-related spikes in the SOFR Spread.

## VIII. Conclusion

As stated previously in the summary of empirical results, there was mixed success in proving hypotheses within this paper. For example, there was proven to be a negative relationship between downward shocks in volume and the spread between ARRs and the EFFR. This relationship, depending on control variables included, changed significantly between normality conditions and illiquid conditions. However, the variation in the rate spreads was not well explained with just shocks in overnight volumes in repo markets and control variables for underlying financial health in banks. The Econometric models that explained the most variation in spreads to the Effective Federal Funds Rate were the models that included the lagged spread variables, in which most of the variation was explained by the additional lagged variable. Within these models, most variables of importance become less statistically significant and relevant to the explanation of spread variation. Even so, with the results from both SOFR and BSBY, we can conclude that the first test hypothesis was moderately proven with a few key conditions.

Oppositely, the second test hypothesis in this paper was staunchly rejected by the Econometric tests run. Stated previously in the paper, the goal was to find a near-zero correlation within alternative reference rates that could have served as a back-up benchmark rate. This could have been helpful

when a market-determined rate, such as SOFR, strays too far from true funding costs and no longer meaningfully represents the overnight funding costs of national and regional banks. It was thought that, since the Ameribor rate of the American Financial Exchange was a regional bank rate with an implied credit spread, it would have less correlation with SOFR and BSBY. However, the lowest correlation in rates was found between SOFR and BSBY, and even then, the correlation was still a very high 78.7%. Because of these results, the second hypothesis has been disproven and there is no application in a dual benchmark solution for these three rates.

An interesting note, apart from the primary study of this paper, is that results diverge from the paper that this study is modeled after by a fair amount. The *Quarter* and *Year* variables were included due to their inclusion in the paper by Klingler and Syrstad (2020). All three date indicator variables were proven to be statistically significant and positive in the SOFR Spread studies. However, both *Quarter* and *Month* variables were insignificant in all BSBY Spread tests. One possible explanation for this divergence is the underlying assets that are being traded. For SOFR, the instruments used in transactions are directly influenced by Federal Reserve announcements and policies. The assets used in the calculation of BSBY, Commercial Paper and Certificates of Deposit, are less influenced by any policy changes from the

Federal Reserve. It would stand to reason, then, that BSBY is relatively unaffected by those policy announcement dates.

However, even though the tests within this paper show that a dual benchmark couldn't work between these three rates, it doesn't preclude the notion that it couldn't work in general. There are many other published alternative reference rates that could theoretically work in tandem with SOFR and BSBY. Further topics of research that could build on this paper could test more alternative rates, doing a deeper dive into the drivers of said rates and working within those drivers to find less correlation among them. In the Econometric tests above, it was found that the drivers of the three rates in question were very similar: they all stemmed from the funding needs of banks, whether regional, national, or international.

Furthermore, although the illiquid shocks in overnight volumes were found to be statistically significant in some cases, there shocks were only tested on overnight rates. It would be an interesting addition to the research here to find the effects on the term rates determined from these overnight rates and whether there is still a significant impact on longer maturity rates. The term rates for both SOFR and BSBY are calculated by weighted averaging throughout the calculation period, so the overnight rates have an impact (albeit a small impact) on the calculation of the larger term rates. Because many of the financial contracts that use SOFR and BSBY use their term rates,

it would be important to know the impacts that are drawn out from the overnight spikes.

It's apparent that more goes into ARR Spread spikes than just illiquid shocks to transaction volumes. However, much of the variation in spikes during illiquid crises can be attributed to shocks in volume, relative financial health, and changes in activity in other markets. It will be crucial to find methods to "smooth" alternative rates for the calculation of term rates in the future to make sure that market participants and market volumes don't weigh too much on the calculation of said rates.

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## X. Appendix

*Exhibit 19: F-Test for Coefficient Difference in First SOFR Spread Test*

| **F-Test for Coefficient Difference** |
|---|
| (1) ChangeinONVolume - Change_in_VolSigma = 0 |
| **F(1, 1863) = 11.62** |
| **Prob > F = 0.0007** |

*Exhibit 20: F-Test for Coefficient Difference in Second SOFR Spread Test*

| **F-Test for Coefficient Difference** |
|---|
| (1) ChangeinONVolume - Change_in_VolSigma = 0 |
| **F(1, 1856) = 7.89** |
| **Prob > F = 0.005** |

*Exhibit 21: F-Test for Coefficient Difference in First BSBY Spread Test*

| **F-Test for Coefficient Difference** |
|---|
| (1) ChangeinONVolume - Change_in_VolSigma = 0 |
| **F(1, 1523) = 3.54** |
| **Prob > F = 0.0600** |

*Exhibit 22: F-Test for Coefficient Difference in Second BSBY Spread Test*

| **F-Test for Coefficient Difference** |
|---|
| (1) ChangeinONVolume - Change_in_VolSigma = 0 |
| **F(1, 1516) = 3.93** |
| **Prob > F = 0.0478** |