IMPENDING LIBOR CESSATION AND ASSESSMENT OF ALTERNATIVE REFERENCE RATES

by

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ABSTRACT

Created in 1969, LIBOR has exponentially grown into the standard benchmark rate used in financial instruments with floating interest rate structures. Within the past decade, the rate has been under a great deal of scrutiny due to various LIBOR manipulation claims. After 2021, LIBOR will be discontinued, and a replacement rate will need to be found for the approximately $200 trillion in financial instruments that currently depend on LIBOR. Recently, governments have proposed replacement rates, called alternative reference rates, to be established for various currencies. This thesis explores (i) if these proposed alternative reference rates are good replacements for LIBOR, (ii) what established rates could be good replacements for LIBOR, and (iii) if there is statistical evidence for LIBOR manipulation in the past. Through various regressions and qualitative analysis, the thesis concludes that alternative reference rates are acceptable replacements for LIBOR. In addition, the thesis reports that existing rates, such as the U.S. Treasury Constant Maturity rate, may also be seen as acceptable alternatives. Lastly, the thesis finds that there is statistical evidence for historical LIBOR manipulation, so there is a need for LIBOR's replacement.

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INTRODUCTION

There are currently around $200 trillion of securities that are priced off or derived from the London Interbank Offered Rate (LIBOR). LIBOR was created in 1969 to represent the average cost of borrowing for a bank borrowing in the unsecured market so that it could be used for overseas lending. The rate it is determined by surveying approximately 20 banks that sit on a bank panel. LIBOR is derived from ~$500mm in daily trading volumes on average, volumes that are significantly lower than the ~$200tn in securities that LIBOR serves. Given that the surveyed banks also hold contracts that are based on LIBOR, the banks can monetarily benefit from over or under-reporting the rate. Unsurprisingly, there have been instances of past manipulation.

Due to the many cases of manipulation in LIBOR by many of the banks that are surveyed to determine an accurate day-to-day LIBOR rate, there has been a push to replace LIBOR. Recently, it was announced that the Financial Conduct Authority (FCA) will no longer require panel banks to provide answers to the rate surveys by the end of 2021. So, after 2021, it is expected that LIBOR will be going away. This produces a great need for a replacement rate and answers to many questions regarding the active replacement of LIBOR for legacy contracts. There have been many proposed replacements, such as using the proposed Alternative Reference Rates (ARRs), Federal Funds Rate, U.S. Constant Maturity Treasury Rates, etc.

This thesis will analyze the proposed government Alternative Reference Rates as well as several other rates to determine which rates may be acceptable alternatives to LIBOR. Additionally, this thesis will investigate whether there is statistical evidence for the manipulation of LIBOR in the past. Moving forward, it is greatly important to determine an alternative rate that can be (i) used in derivatives, loans, securities, and mortgages contracts and (ii) would be much more difficult to manipulate.

RESEARCH QUESTIONS

There focus of this thesis will be to provide background information and analysis to answer the following three research questions:

1. Would proposed Alternative Reference Rates, such as the United States' Secured Overnight Financing Rate (SOFR), make good replacements for LIBOR?
2. What other, established rates could be acceptable LIBOR replacements? Some established rates include the U.S. Effective Federal Funds Rate (EFFR), the U.S. Constant Maturity Treasury (CMT) Rate, and the AA Financial Commercial Paper (CP) Rate.
3. Is there statistical evidence for historical LIBOR manipulation?

LITERATURE REVIEW

London Interbank Offered Rate

LIBOR is the London Interbank Offered Rate and is a rate that represents the average cost of borrowing for a large bank borrowing in the unsecured market (Duffie, 2015). The rate was created in August 15, 1969 in a J.P. Morgan loan design and was used on June 5, 1970 when Manufacturers Hanover Ltd. announced a $100 million 5-year loan that included a floating rate structure (J.P. Morgan, 2019). A floating rate structure means that the loan’s interest rate will increase or decrease depending on what LIBOR is at—so, if LIBOR moves higher then the interest rate will increase. Floating rate structures are widely used to transfer interest rate risk in loans onto the borrower.

Started with the intention for just a few banks to lend money to overseas clients, LIBOR grew quickly and became an essential part of the derivatives market (J.P. Morgan, 2019). Nowadays, the most frequent use of LIBOR is as a benchmark rate for financial instruments with floating rate structures (Duffie, 2015). LIBOR is considered the standard benchmark rate and is the rate which about $200 trillion in loans, derivatives, mortgages, and securities are derived. This $200 trillion is around 10 times current U.S. GDP, and about $190 trillion are derivatives instruments (J.P. Morgan, 2019 and Held, 2019). When created, the rate was not intended to become such a wide-spread market standard, as LIBOR is calculated from only approximately $500 million in daily transactions (J.P. Morgan, 2019).

In total, there are 35 rates for LIBOR published each U.K. business day with different currencies and maturities. For example, there is a U.S. Dollar LIBOR with a 12-month maturity and there is also a Japanese Yen LIBOR with a 3-month maturity. There are numerous currencies that LIBOR is reported in. The active currencies include the U.S. Dollar, Euro, British Pound

Stirling, Japanese Yen, and the Swiss Franc, and inactive currencies include the Australian Dollar, Canadian Dollar, New Zealand Dollar, Danish Krone, and Swedish Krona. Similarly, there is a multitude of maturities reported for LIBOR. Active maturities include 1 day, 1 week, 1 month, 2 months, 3 months, 6 months, and 12 months. The pairings of these different maturities and currencies is integral to the rapid expansion of LIBOR, as financial instruments can use these rates with differing currencies and maturities as benchmark rates (Hou, 2014).

LIBOR Calculation

LIBOR is determined by surveying just 11 to 16 banks who sit on a reference panel for each aforementioned active currency. This survey is intended to determine the rate that large banks would be able to borrow at for particular currencies and tenors in the unsecured market (Intercontinental Exchange). The composition of the LIBOR bank panel is provided in the table below:

Figure 1: LIBOR Bank Panel Composition (Intercontinental Exchange)

Panel Composition						
#	**Bank**	**USD**	**GBP**	**EUR**	**CHF**	**JPY**
1.	Bank of America N.A. (London Branch)	✔				
2.	Barclays Bank plc	✔	✔	✔	✔	✔
3.	BNP Paribas SA (London Branch)		✔			
4.	Citibank N.A. (London Branch)	✔	✔	✔	✔	
5.	Cooperatieve Rabobank U.A.	✔	✔	✔		
6.	Crédit Agricole Corporate & Investment Bank	✔	✔			
7.	Credit Suisse AG (London Branch)	✔		✔	✔	
8.	Deutsche Bank AG (London Branch)	✔	✔	✔	✔	✔
9.	HSBC Bank plc	✔	✔	✔	✔	✔
10.	JPMorgan Chase Bank, N.A. (London Branch)	✔	✔	✔	✔	✔
11.	Lloyds Bank plc	✔	✔	✔	✔	✔
12.	Mizuho Bank, Ltd.		✔	✔		✔
13.	MUFG Bank, Ltd	✔	✔	✔	✔	✔
14.	National Westminster Bank plc	✔	✔	✔	✔	✔
15.	Royal Bank of Canada	✔	✔	✔		
16.	Santander UK Plc		✔	✔		
17.	Société Générale (London Branch)		✔	✔	✔	✔
18.	Sumitomo Mitsui Banking Corporation Europe Limited	✔				✔
19.	The Norinchukin Bank	✔				✔
20.	UBS AG	✔	✔	✔	✔	✔

Each of these banks are asked to answer the following survey question: "At what rate could you borrow funds, were you to do so by asking for and then accepting interbank offers in a reasonable market size just prior to 11am?" The ambiguity with wordings such as "reasonable market size" leave the question up to the interpretation of the answering bank. Additionally, the answering banks are not required to produce evidence of their answers—so banks can easily claim to borrow at lower or higher costs (Hou, 2014).

In an attempt to resolve some of these shortcomings, the survey answers from each bank are taken and adjusted in the calculation of LIBOR. The top and bottom 25% of respondents' answers are removed from consideration and the remaining 50% of survey responses are used to calculate LIBOR based on the trimmed arithmetic mean of the remaining values. So, if there are 14 contributing banks for U.S. Dollar 3-month borrowing rates then the highest and lowest 3 rates are disregarded, and the remaining 8 contributed values are used to determine the U.S. Dollar 3-month LIBOR (Intercontinental Exchange).

Historical LIBOR Manipulation

As may be expected from an interest rate that influences $200 trillion in financial instruments and is driven by only 20 banks, there have been multiple cases of manipulation and collusion in the LIBOR setting process. A widespread international investigation began in 2012, looking into LIBOR manipulation by banks such as Deutsche Bank, Rabobank, UBS, and the Royal Bank of Scotland that stemmed back as early as 2003. Banks, such as these, have been fined greater than $9 billion by the UK, U.S., and E.U. for LIBOR manipulation (McBride, 2016).

After the 2007-2008 financial crisis, clear signs of LIBOR manipulation began to spring up. Banks were falsely reporting on LIBOR surveys in order to make money on interest rate swaps and various loans. It has also been suggested that banks were misreporting LIBOR during the financial crisis to indicate greater financial strength. One of the reasons for such rampant LIBOR manipulation was because "[b]anks were asked to estimate the rate at which they could borrow from other banks, not rates at which they actually borrowed" (Held, 2019). There are three examples of such manipulation that have been widely reported:

The first is in two instant messaging conversations between traders, shown below. One, on the left, shows the conversation between Jezri Mohideen, a head of yen products in Singapore, and several traders, including Danziger and Tan. The second, on the right, is depicts a conversation between Scott Nygaard, a global head of the RBS London treasury markets, and Tan, a trader (Tan, 2012).

August 21, 2017	**March 27, 2008**
Mohideen: "What's the call on [LIBOR]"	*Tan:* "We want high fix in [3-month LIBOR]"
Danziger: "Where would you like it"	*Tan*: "Neil is the one setting the yen [LIBOR] in London now and for this week and next."
Trader: "Mixed feelings, but mostly I'd like it lower so the world starts to make a little sense."	*Nygaard:* "Go Neil"
Tan: "The whole [Hedge Fund] world will be kissing you instead of calling me if [LIBOR] move lower"	*Nygaard:* "Hahahaha."
Danziger: "OK, I will move the curve down 1 basis point, maybe more if I can"	(Tan, 2012)

The second example of LIBOR manipulation is in banks' manipulation of LIBOR with regards to Adjustable-Rate Mortgages (ARMs). ARMs are loans that have changing interest rates, which start with lower monthly payments and increase throughout the loan (The Federal Reserve Board). These ARMs were set to have floating interest rates based on LIBOR that reset on the first of the month. It was found that LIBOR was being set higher on the first day of each month so that banks would receive more revenue from the interest payments on ARMs. This was happening because banks were reporting higher rates in their surveys, driving LIBOR up by multiple basis points, on average, on the first day of each month (Touryalai, 2012).

A third example of LIBOR manipulation is in interest rate swaps that banks were providing to municipalities. In April 2012, municipalities would purchase LIBOR interest rate swaps and take the fixed end in order to hedge the sales of municipal bonds. Banks would take the floating end of the interest rate swap. It was found that banks were reporting lower rates on the fixing dates of these interest rate swaps in order to drive LIBOR down. Banks were manipulating LIBOR down so that they would not have to pay municipalities as much on the fixing date—or so that municipalities would need to pay more on the fixing date. Peter Shapiro, a managing director at Swap Financial Group, estimated that this sort of manipulation cost participating municipalities greater than $6 billion (Preston, 2012).

On July 27, 2012, an important article was posted by Douglas Keenan in the Financial Times, titled “My thwarted attempt to tell of [LIBOR] shenanigans”. In this article, Keenan claimed that LIBOR manipulation “may have been common practice since at least 1991” (Keenan, 2012). Articles, such as this, brought a great deal of attention to LIBOR manipulation and caused more investigation to be done on the matter.

Upcoming LIBOR Cessation

The Financial Conduct Authority (FCA) has been regulating LIBOR since April 2013. On July 27, 2017, Andrew Bailey, the chief executive of the FCA, gave a speech at Bloomberg London and announced that there will be a transition away from LIBOR. Bailey stated that many panel bank participants have been uneasy about submitting surveys and setting LIBOR, given the small amount of transaction volume that the rate is based on. For the past few years, the FCA has been persuading banks to continue participating in the surveys, given that a sudden change away from LIBOR could be harmful to the market. Recently, panel banks have agreed to continue reporting rates in LIBOR surveys until the end of 2021 (Bailey, 2017).

After 2021, panel banks will no longer submit to the LIBOR surveys and LIBOR will likely be discontinued. Due to the historical LIBOR manipulations and small transaction volume that the rate is derived from, the FCA determined that the use of LIBOR was not sustainable. Additionally, given the large number of contracts that use LIBOR as the benchmark rate, the FCA wanted to give market participants an ample amount of time to either switch to new benchmark rates or redefine LIBOR and to replace its current methodology using alternative reference rates (Bailey, 2017).

U.S. Constant Maturity Treasury Rate

The United States Constant Maturity Treasury (CMT) Rate is calculated as the average yield on U.S. Treasury securities, adjusted to a constant maturity. The source yield for the CMT rate comes from actively traded Treasury securities in OTC market (Moody's Analytics). The CMT rate is calculated by using a quasi-cubic hermite spline function with the yields on these actively traded U.S. Treasury securities. Essentially, what this means is that the U.S. Treasury is fitting a third-degree polynomial function on the yield curve in order to calculate continuous predictions of different yields at different maturities. The Treasury does, however, have the right to change the yield curve if they see fit by (i) removing or adding different inputs or (ii) changing the calculation methodology (U.S. Department of the Treasury).

Using the quasi-cubic hermite spline function, the U.S. Treasury calculates and reports various yields at fixed maturities (U.S. Department of the Treasury). The reported yields include the CMT rate for 1-month, 3-month, and 6-month yields as well as 1-year, 2-year, 3-year, 5-year, 7-year, 10-year, 20-year, and 30-year yields. The U.S. Treasury is able to estimate these values using existing Treasury securities even if there are no securities with the exact tenure outstanding thanks to the applied function (Moody's Analytics).

U.S. Treasury Effective Federal Funds Rate

The Effective Federal Funds Rate (EFFR) is the interest rate that banks are willing to lend to each other overnight. The rate "is calculated as a volume-weighted median of overnight federal funds transactions". Overnight transactions are defined to be transactions that (i) are traded and settled on the same date and (ii) mature on the next day after the trade date. Additionally, the volume-weighted median indicates that the overnight federal funds transactions are ranked from highest to the lowest in terms of interest rate. Then, the volumes of each of these rates are used to identify which rate is at the 50th percentile for total cumulative volumes (Federal Reserve Bank of New York, 2019).

The Federal Open Market Committee (FOMC) sets a target range for the federal funds market (Federal Reserve Bank of New York, 2019). Using this target range, the Federal Reserve utilizes varying monetary policy by altering reserve supplies in order to adjust the federal funds rate to be within the range. The accuracy of the federal funds rate adjustment depends on the Federal Reserve's ability to correctly predict bank reserve demand. It has been reported that "interbank payments play a significant role in determining the level and volatility of the daily federal funds rate" (Furfine, 1998).

AA Financial Commercial Paper Rate

The AA Financial Commercial Paper (CP) Rate represents the interest rate on short-term promissory notes issued by AA-rated financial companies. Essentially, these are short-term loans that are below 270 days to maturity that are issued by highly-rated financial institutions. The average maturity for CP is generally around 30 days. Commercial Paper is commonly used as an alternative to borrowing from banks (Board of Governors of the Federal Reserve System, 2017). There are numerous AA Financial CP interest rates that can be quoted for different maturities. Some of the active maturities that can be found on various sources, such as Bloomberg, include overnight, 7-day, 15-day, 30-day, 60-day, and 90-day AA Financial Commercial Paper rates (Bloomberg, 2019).

AA Financial CP rates are transaction-based rates calculated using CP trades settled by The Depository Trust & Clearing Company (DTCC). In the calculation of AA Financial CP rates, the Federal Reserve Board receives data from the DTCC and generates rates using estimated relationships between security maturities and respective interest rates. Trades are weighted by the total transaction size, so smaller trades will have less of an impact on the AA Financial CP rate. The particular econometric methodologies for the calculation of AA Financial CP rates were not provided by the Federal Reserve (Board of Governors of the Federal Reserve System, 2017).

Alternative Reference Rates

Due to the rampant manipulation in LIBOR that has been seen in the past, regulators are emphasizing the need for a shift to other benchmark rates. Organizations across many key currencies have been working to develop new benchmark rates to replace LIBOR, called alternative reference rates (ARRs) or alternative overnight risk-free rates (RFRs). There are five main ARRs that are being developed or are in use: (i) the Bank of England is creating the Reformed Sterling Overnight Index Average (SONIA) for the U.K., (ii) the Federal Reserve Bank of New York released its Secured Overnight Financing Rate (SOFR) for the U.S., (iii) the European Central Bank is developing its Euro Short-Term Rate (ESTER) for the Eurozone, (iv) the SIX Swiss Exchange is using its Swiss Average Rate Overnight (SARON) for Switzerland, and (v) the

Bank of Japan is also using its Tokyo Overnight Average Rate (TONA) for Japan. These ARRs are part of the countries' plans to transition away from LIBOR prior to 2021—similar to LIBOR, each of these rates represent different currencies (Deloitte, 2019).

Where feasible, institutions have been advised to move legacy contracts and transactions from LIBOR to ARRs, such as SOFR or SONIA. Many institutions are working to create amendments for such legacy contracts and transactions that will allow them to easily shift the rate to ARRs in order to minimize the risk of LIBOR's disappearance. Additionally, it is advised that derivatives should be based on ARRs instead of LIBOR—the reason for this is that overnight RFRs are seen as superior for hedging interest rate risks. LIBOR is a rate that intrinsically incorporates credit risk from banks and premiums for loan terms, which weakens it as a hedging tool (Ernst & Young, 2019).

U.S. Secured Overnight Financing Rate

As previously mentioned, the United States' Secured Overnight Financing Rate is the Federal Reserve Bank of New York's ARR that is intended to replace LIBOR. An Alternative Reference Rate Committee (ARRC) was formed with private-market participants to ensure a smooth transition from LIBOR to another benchmark rate. The ARRC's recommended alternative for USD LIBOR is the Federal Reserve Bank's SOFR (Federal Reserve Board, 2019).

The U.S. SOFR is a new rate created on April 3, 2018 that represents overnight borrowing costs for cash collateralized by Treasury securities. SOFR is calculated using actual transactions from (i) tri-party repurchase (repo) transactions reported by the Bank of New York Mellon and (ii) bilateral Treasury repo transaction data collected from the Fixed Income Clearing Corporation (FICC). SOFR represents the volume-weighted median of the collected rates, which is performed in a similar manner to the previously mentioned U.S. Treasury EFFR calculation methodology (Federal Reserve Bank of New York, 2019).

The U.S. Secured Overnight Financing Rate is predicted to be a better benchmark rate than LIBOR because it is calculated based on a market where approximately $800 billion in daily trades occur. Regulators are hoping that loans and derivatives will quickly transition from using U.S. LIBOR to U.S. SOFR in order to decrease the market's reliance and overall importance of LIBOR. It was reported that the Chicago Mercantile Exchange (CME) Group will be releasing SOFR futures trading starting in May 2019. In addition, it has been announced that clearinghouses and dealers are working to offer SOFR interest rate swap trades (Brettell, 2019).

METHODOLOGY

Data Collection

To address the first two research questions regarding rates that would be good replacements for LIBOR as a benchmark rate, I identified four rates that will be analyzed and compared to LIBOR. The first research question asks what proposed alternative reference rates make good replacements for LIBOR. To answer this question, I decided to analyze the United States' chosen ARR, the Secured Overnight Financing Rate. For the second research question that asks what other, established rates could be acceptable LIBOR replacements, I used three common interest rates: the (i) United States Constant Maturity Treasury Rate, (ii) U.S. Treasury Effective Federal Funds Rate, and (iii) the AA Financial Commercial Paper Rate.

In order to address each of my three research questions, I first started my data collection process by pulling historical LIBOR quotes. I pulled daily rates for overnight, 1-month, 3-month, 6-month, and 12-month U.S. LIBOR for the past five years (March 2014 to March 2019) using a Bloomberg Professional terminal. Bloomberg retrieves the historical LIBOR quotes for each of these maturities from the Intercontinental Exchange (ICE) Benchmark Administration. Each of the daily LIBOR quotes that I'll be using throughout my analysis were reported by the ICE Benchmark Administration at 11:45am London time each day (Bloomberg, 2019).

Second, I pulled the daily historical SOFR rates from April 2018 to March 2019 that were published by the New York Fed. Unfortunately, SOFR is a relatively new interest rate so it does not have any historical quotes that go back before April 2018. Additionally, I pulled 1-month and 3-month SOFR futures contract rates that were reported by the Chicago Mercantile Exchange (Bloomberg, 2019). Using overnight SOFR as well as the futures contract rates, I intended to compare this alternative reference rate to overnight US LIBOR as well as 1-month and 3-month LIBOR rates.

For the U.S. Effective Federal Funds Rate, I used Bloomberg Professional to pull the daily EFFR for March 2014 to March 2019 that was released by the New York Federal Reserve. In addition, I pulled the daily 1-month Federal Funds futures contract rate that was reported by the Chicago Board of Trade (CBT). For the U.S. CMT rates, I pulled the daily 1-month, 3-month, 6-month, and 12-month CMT rates that were reported by the United States Treasury. Lastly, I used Bloomberg Professional to pull the 3-month AA Financial CP rates sourced from the United States Federal Reserve (Bloomberg, 2019). As each of these rates are U.S. Dollar interest rates, I will compare these rates to U.S. LIBOR with the same maturity.

Research Methods

In order to determine whether or not interest rates would be an acceptable alternative to LIBOR, I decided to use regressions to determine whether or not a rate has historically tracked LIBOR and to determine if a rate explains the variation in LIBOR. To do this, I established LIBOR as a dependent variable and each of my considered alternative rates (e.g. SOFR, U.S. CMT, etc.) as independent variables in the regressions. The LIBOR rate that is used for the dependent variable always was selected to match the currency and maturity of the independent variable.

For each of the variables considered, I performed six regressions of the considered variable on LIBOR. Of these six regressions, I used two types: three of the regressions were “regular” regressions with an intercept and slope, and the other three regressions were “no-constant” regressions that set the intercept at zero. These regressions were performed using statistical analysis functions on STATA and Excel. The three regression methodologies that were used for “regular” and “no-constant” regressions are described on the next page.

1. **Levels on levels regression** – A “levels on levels” regression entails the actual rates of the independent variable and dependent variable being regressed against each other. For example, in a “levels on levels” regression of overnight EFFR on overnight U.S. LIBOR, the actual interest rates for EFFR would be regressed on the actual rates of overnight U.S. LIBOR. “Levels on levels” regressions are used to determine the correlation, beta coefficient, and intercept of the independent variable regressed on LIBOR. In general, “levels on levels” regressions report higher R^2 values.
2. **Daily percent change regression** – “Daily percent change” regressions are performed by regressing the daily percent change of the independent variable on the daily percent change of the dependent variable. This regression tries to explain the daily percent change in U.S. LIBOR using the daily percent change in the independent variable—so, if the EFFR increased by 3% today then we would estimate how much to expect U.S. LIBOR to go change by in percentage terms, on average. “Daily percent change” regressions will generally have much lower R^2 and t-statistics.
3. **One-day delayed percent change regression** – The “one-day delayed percent change” regression methodology takes the daily percent change of the *previous* day for the independent variable and regresses it on the daily percent change of the *current* day of the dependent variable. So, for example, if the EFFR increased by 5% today then we would estimate how much to expect U.S. LIBOR to increase by tomorrow in percentage terms, on average. This is the last regression methodology that was performed to determine whether existing interest rate changes predict future changes of LIBOR. “One-day delayed percent change regressions” have lower R^2 and t-statistics and rarely are statistically significant.

The two below figures depict an example of how "levels on levels" and "daily percent change" regressions place a fitted line through the two-variable scatterplot for "no-constant regressions". This example utilizes the EFFR regressed on overnight LIBOR.

Figure 2: No-constant "levels on levels" regression for EFFR on overnight LIBOR

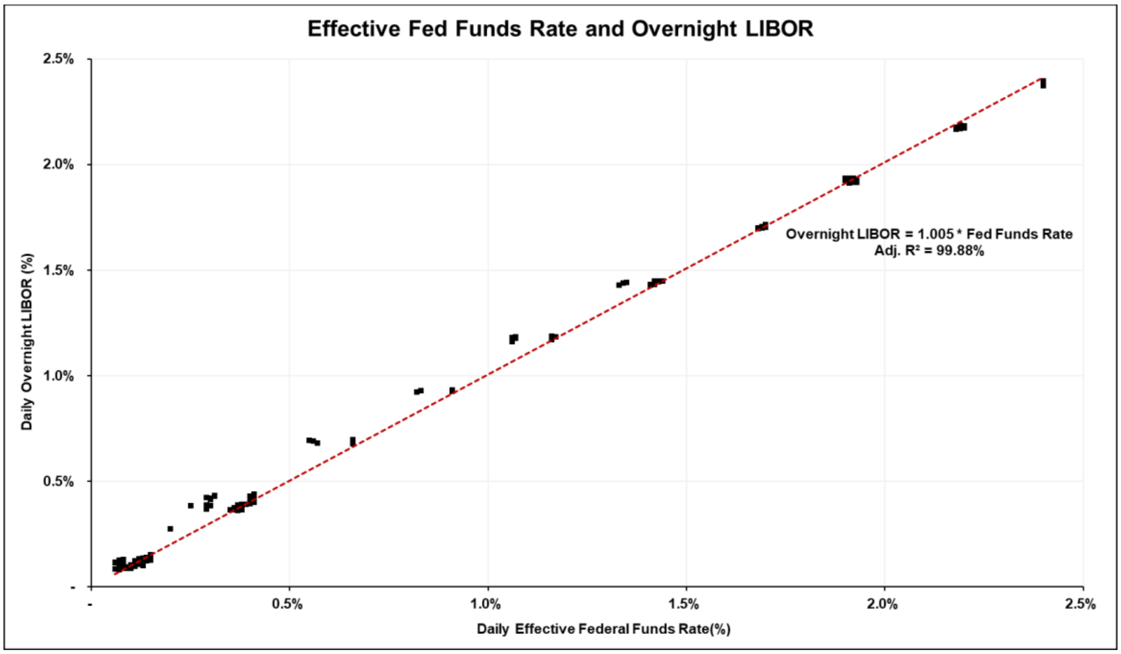
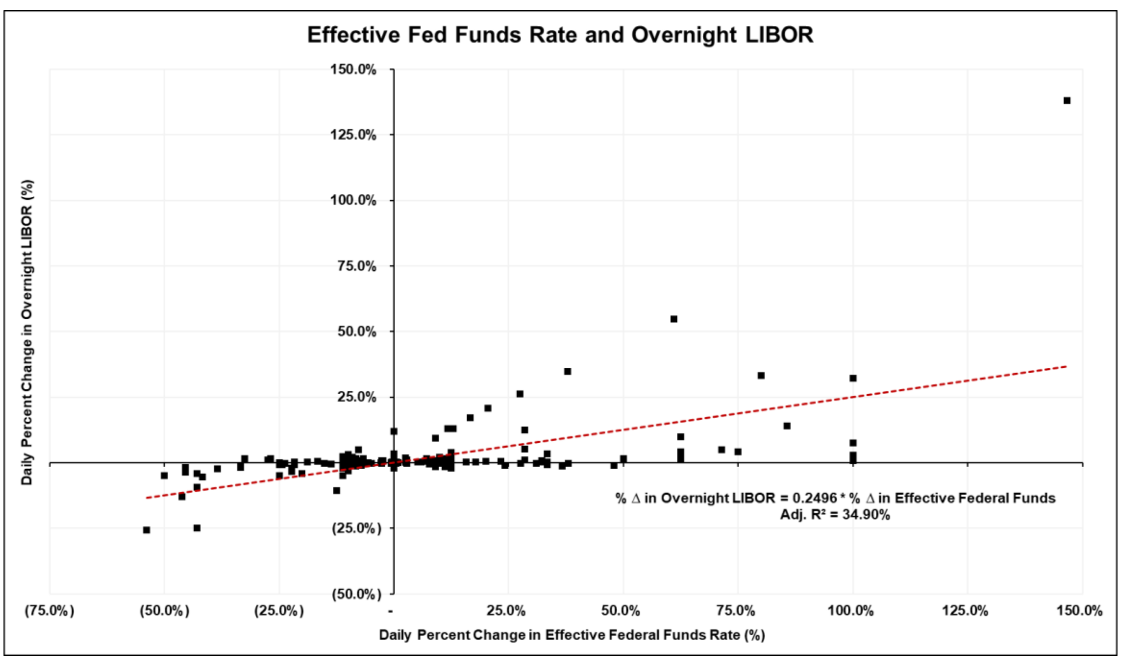


Figure 3: No-constant "daily percent change" regression for EFFR on overnight LIBOR



In order to answer my third research question of whether there is statistical evidence for historical LIBOR manipulation, I conducted multiple one-sample variance-comparison tests. One-sample variance-comparison tests analyze whether two variables have different variances (or standard deviations). I ran this test for overnight U.S. LIBOR, overnight EFFR, 3-month U.S. CMT, and 30-day AA Financial CP rates. For each of these variables, I divided the data into two sets with 75 observations each: one set with rates from February 18, 2011 to July 20, 2012 and one set with rates from July 27, 2012 to December 27, 2013.

The reason for this particular data division is that an important article was released by the Financial Times on July 27, 2012 that called out many banks for manipulating LIBOR, as previously discussed in the literature review. By running a multiple one-sample variance-comparison test, I wanted to check whether the fluctuation of LIBOR was greater before the release of this Financial Times article. I hypothesized that there would be greater fluctuations in LIBOR—and therefore a greater standard deviation—before the article because banks would likely have needed to limit the LIBOR manipulation after the article was released. Additionally, I performed the one-sample variance-comparison test on three other rates in order to see if the hypothesized change in standard deviation was present in other rates as well.

Lastly, I looked at what the difference between the overnight LIBOR and effective federal funds rate was over the last fifteen years to see if there were any interesting trends. In particular, I wanted to see what the difference was during the ’07-’08 financial crisis. Due to the fact that there were reports that banks were manipulating LIBOR higher in an attempt to show strength, I hypothesized that the difference between the EFFR and LIBOR would increase dramatically before the recession.

RESULTS

For my first research question regarding whether ARRs (e.g. SOFR) are good replacements for LIBOR, I looked at my various regressions of SOFR on U.S. LIBOR (see Appendix II, Regressions 1-3). My “levels on levels” regression of overnight SOFR on overnight U.S. LIBOR was statistically significant for both the regular and no-constant regressions. The regular “levels on levels” regressions reported an adjusted R^2 of 92.1% and has an intercept and slope coefficient of 0.232 and 0.875 with t-statistics of 6.589 and 52.000, respectively. Similarly, the no-constant “levels on levels” regression yielded an adjusted R^2 of 99.4% and has a slope coefficient of 0.984 with a t-statistics 414.481. This no-constant “levels on levels regression” shows that if SOFR increased by 100 basis points then overnight U.S. LIBOR should increase by 98.4 basis points, on average. Additionally, the high adjusted R^2 of 99.4% in the no-constant “levels on levels” regression says that 99.4% of the variation of overnight U.S. LIBOR is explained by SOFR. It is also important to note that the extremely high t-statistics in both the regular and no-constant “levels on levels” regressions show that it would be extremely unlikely for this analysis not to hold true over time—providing confidence for the statistical significance of the regressions.

My regular and no-constant “daily percentage change” regressions for SOFR on U.S. LIBOR provided additional evidence that SOFR is a suitable replacement for U.S. LIBOR. The regular “daily percentage change” regression provided an adjusted R^2 of 13.0% and has an intercept and slope coefficient of 0.001 and 0.175 with t-statistics of 1.534 and 5.970, respectively. This lower adjusted R2 value is to be expected, as described in the methodology section. Additionally, the low intercept of 0.001 provides evidence for a no-constant regression being more useful in analyzing the “daily percent change regressions”. My no-constant “daily percent change” regression reported an adjusted R^2 of 13.2% and has a slope coefficient of 0.177 with a t-statistics

6.048. This implies that if SOFR changed by 1.00% in one day then U.S. LIBOR is expected to change by 0.18%.

The high t-statistics for the "daily percent change" and "levels on levels" regressions show that SOFR has, historically, tracked U.S. LIBOR. My "one-day delayed percent change" regression carried little statistical significance, allowing me to make no conclusion on whether changes to SOFR today would impact future changes in U.S. LIBOR. Additionally, the 1-month and 3-month SOFR futures contract rates carried fluctuating statistical significances for the three regression methodologies. This is likely due to the limited data on the futures contracts, as they were released recently.

Turning to the second research question on whether other, existing rates could be good replacements for LIBOR, I considered many regressions of U.S. EFFR, U.S. CMT, and AA Financial CP rates on U.S. LIBOR. The outputs to all of these regressions can be viewed in Appendix II Regressions #4-10. A summary of the results for each of these regression sets is provided below:

1. **United States Effective Federal Funds Rate** – All six of the regressions for overnight EFFR on overnight U.S. LIBOR were statistically significant, with the no-constant "levels on levels" regression outputting an adjusted R^2 of 99.9%, slope coefficient of 1.005, and t-statistic of 1762.322. Additionally, all six of the regressions for 1-month Federal Funds futures contract rates on 1-month U.S. LIBOR also provided statistically significant intercepts and slope coefficients—though, with lower adjusted R^2 figures. This implies that it is likely overnight EFFR is not only highly correlated to overnight U.S. LIBOR, but that current changes in overnight EFFR can also be seen to predict next-day changes in

overnight U.S. LIBOR, on average. These findings evidence my theory that overnight EFFR may be a suitable replacement for U.S. LIBOR.

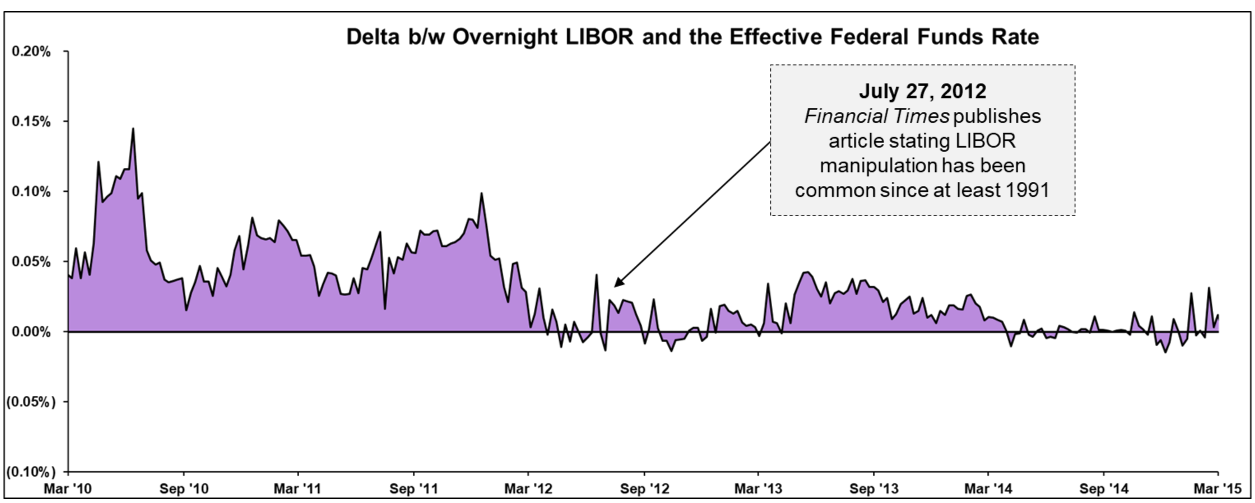
2. **United States Constant Maturity Treasury Rate** – I performed a multitude of using U.S. CMT rates with different maturities. I implemented six regressions each for 1-month U.S. CMT, 3-month CMT, 6-month CMT, and 12-month CMT rates on U.S. LIBOR with the same maturity. For the regressions of 1-month U.S. CMT on 1-month U.S. LIBOR, the "levels on levels" regressions produced statistically significant intercepts and slope coefficients, but the "daily percent change" and "one-day delayed percent change" regressions yielded extremely low—or negative—adjusted R^2 values and did not have statistically significant intercepts and slope coefficients. The "levels on levels" regressions for the 3-month CMT, 6-month CMT, and 12-month CMT rates on U.S. LIBOR of the same maturities produced adjusted R^2 values of 96.6%, 95.4%, and 94.3%, respectively. Additionally, the 3-month CMT, 6-month CMT, and 12-month CMT rates provided statistically significant intercepts and slope coefficients for both the "levels on levels" and "daily percent change" regressions. The 6-month CMT and 12-month CMT rates additionally yielded statistically significant intercepts and slope coefficients for the "one-day delayed percent change" regressions. So, these findings show that the U.S. CMT rate can be a good substitute for U.S. LIBOR, but it also yielded lower adjusted R^2 values for its regressions than U.S. EFFR.

3. **AA Financial Commercial Paper Rate** – The regular and no-constant "levels on levels" regressions for 3-month AA Financial CP rates on 3-month U.S. LIBOR both produced an adjusted R^2 of 99.5% and yielded statistically significant intercepts and slope coefficients. However, the regular and no-constant "daily percent change" regressions produced

negative adjusted R^2 values and did not yield statistically significant intercepts and slope coefficients. This shows that the daily percent changes in 3-month AA Financial CP rates do not necessarily predict 3-month U.S. LIBOR at all. Surprisingly, the regular and no-constant "one-day delayed percent change" regressions produced slightly positive adjusted R^2 values as well as statistically significant intercepts and slope coefficients. This implies that 3-month AA Financial CP rates do a better job predicting future changes in 3-month U.S. LIBOR than predicting same-day changes.

Addressing my third research question regarding if there is statistical evidence for historical LIBOR manipulation, I first examined the difference between the U.S. EFFR and overnight U.S. LIBOR before and after July 27, 2012. As previously discussed, a major article published on July 27, 2012 brought a great deal of attention to LIBOR manipulation, so I hypothesized that the differences between overnight LIBOR and the EFFR would change after the article was published. A figure displaying the difference between these two rates is provided below. Notice that there seems to be a much greater delta prior to July 27, 2012 than after the article was published.

Figure 4: Difference between overnight U.S. LIBOR and the EFFR from Mar '10 to Mar '15



To statistically test if there were a change in the reporting of LIBOR after the article was published, I performed a one-sample variance-comparison test for overnight U.S. LIBOR and compared it with one-sample variance-comparison tests performed on the EFFR, U.S. CMT rate, and AA Financial CP rate. Using this test, I was looking to determine if the standard deviation of LIBOR was different before and after the July 27th article was published—and, additionally, if this held true for only LIBOR or for the other rates as well. The output for the one-sample variance-comparison test of overnight U.S. LIBOR is provided below, and the outputs for the other three rates are provided in Appendix III.

Figure 5: One-sample variance-comparison test of overnight U.S. LIBOR

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
lafter	75	.0152973	.0016206	.0140352	.0120681	.0185265
lbefore	134	.0500299	.002492	.0288464	.0451009	.0549588
combined	209	.037566	.0020532	.0296824	.0335183	.0416137

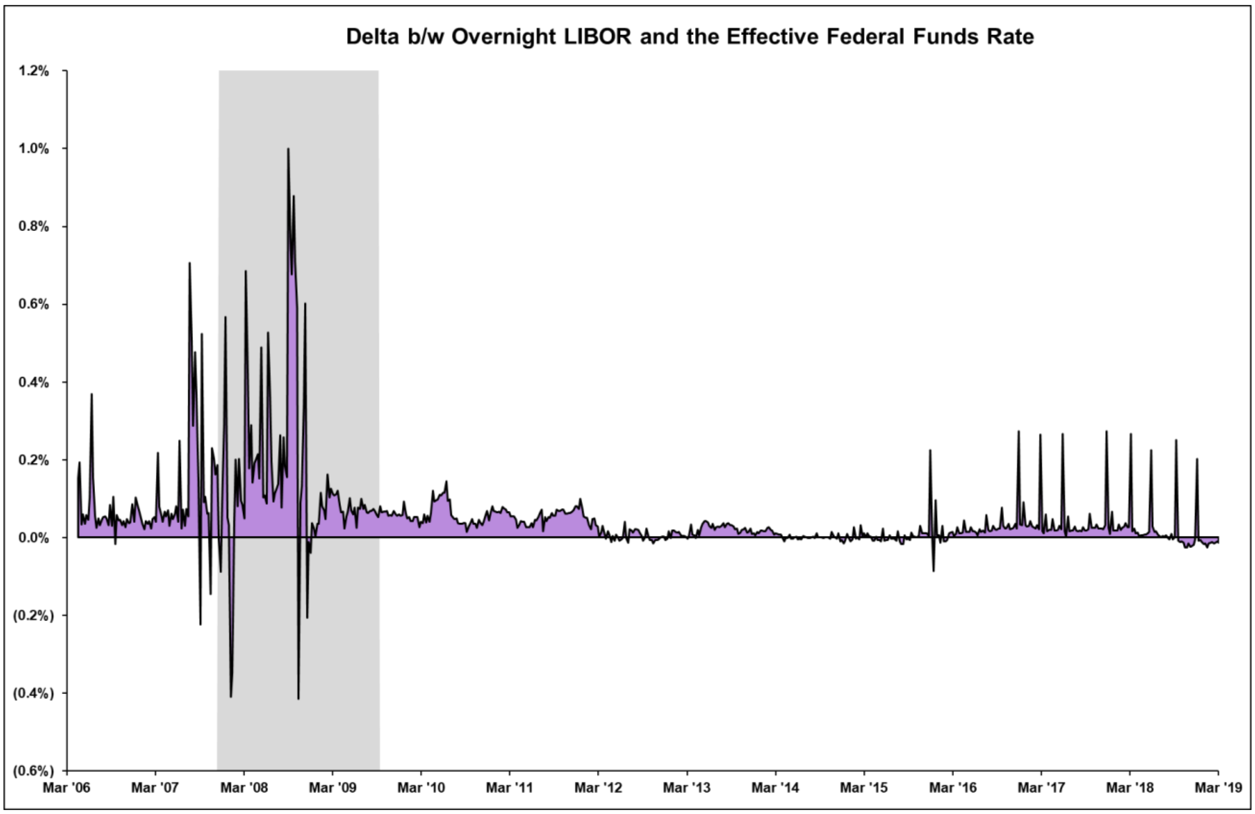
```
    ratio = sd(lafter) / sd(lbefore)                          f =   0.2367
Ho: ratio = 1                                   degrees of freedom =  74, 133

    Ha: ratio < 1              Ha: ratio != 1                 Ha: ratio > 1
  Pr(F < f) = 0.0000       2*Pr(F < f) = 0.0000           Pr(F > f) = 1.0000
```

The above test shows a p-value of "0.0000", which leads to the conclusion that overnight U.S. LIBOR's standard deviation for the period prior to July 27, 2012 is different than the standard deviation for the period after July 27, 2012. Additionally, looking at the same test with the three other rates (provided in Appendix III), this difference in standard deviations does not hold true for the EFFR or U.S. CMT rates—and the p-value for AA Financial CP rates, while significant, is higher than that of overnight U.S. LIBOR. While we cannot conclude with certainty that this implies manipulation in U.S. LIBOR reporting, there is certainly statistical evidence that supports the theory.

In addition to these tests, I decided to look at the difference between overnight U.S. LIBOR and the EFFR over the past fifteen years to see how the delta changes over time and during the Great Recession. As previously mentioned, it was theorized that banks were colluding to report higher LIBOR prior to the financial crisis to falsely signal strength. While no statistical tests were performed to verify, it does, in fact, look like there was a drastic increase in the delta between overnight LIBOR and the EFFR before and during the ’07-’08 financial crisis (shown in grey).

Figure 6: Difference between overnight LIBOR and the EFFR over the past 15 years



CONCLUSION

LIBOR is an extremely important benchmark rate that affects approximately $200 trillion in loans, derivatives, mortgages, and securities. Even given its importance, there has been limited academic research on LIBOR in the past. As LIBOR reporting is likely to be discontinued after 2021, there is great need for an alternative benchmark rate that can replace LIBOR moving forward. This thesis attempts to provide information regarding what rates may be acceptable substitutes and whether there is a need for U.S. LIBOR replacement.

Many countries have created alternative reference rates in order to replace LIBOR for various currencies after 2021. The United States ARR, SOFR, was created in April 2018 with the intention of becoming the next standard USD benchmark rate. This thesis has shown that SOFR is, in fact, a good replacement rate for LIBOR. It is a transaction-based rate that is calculated using approximately $800 billion in transaction volumes, meaning that it would be much more difficult to manipulate than LIBOR. Additionally, multiple regressions performed on SOFR and overnight U.S. LIBOR provide evidence for SOFR being highly correlated to and predicting U.S. LIBOR. Given all of this, we can conclude that SOFR is an acceptable alternative to U.S. LIBOR.

To consider if there are any other, established rates that can be acceptable LIBOR replacements, this thesis performed many regressions using the EFFR, AA Financial CP, and U.S. CMT rates on U.S. LIBOR of varying maturities. Given the high adjusted R^2 as well as high statistical significance in the intercept and slope coefficients of the performed regressions, we can see that there are other, established rates that would be acceptable alternatives to LIBOR. The best of these rates would be the United States Effective Federal Funds Rate, given that it held the highest adjusted R^2 values across the performed regressions as well as the highest statistical significance in its intercepts and slope coefficients. Historically, EFFR has tracked overnight U.S.

LIBOR better than SOFR. Additionally, EFFR has an existing futures market that could be used to provide rates with varying maturities, while SOFR's futures contracts have just recently been created. The U.S. CMT rate also appears to be a potentially acceptable replacement rate for U.S. LIBOR, but this thesis concludes that the EFFR would be the best replacement of the considered rates.

Lastly, this thesis analyzed whether there is statistical evidence for historical LIBOR manipulation using one-sample variance-comparison tests. As expected, given the results for these tests, this thesis concludes that there is statistical evidence for manipulation in the rate. Additionally, this thesis showed (i) many examples of manipulation that have previously been reported and (ii) that it is likely banks were manipulating LIBOR to falsely signify strength before the Great Recession. So, overall, this thesis concludes that historical manipulation in LIBOR is extremely likely and that there is a great need for an acceptable replacement rate.

CONTINUED RESEARCH

There are many areas through which this thesis can be expounded upon. If I were to continue research on the topic, I would focus on a few key areas:

- As of April 1, 2019, the Ice Benchmark Association transitioned all of the LIBOR panel banks to a new, waterfall calculation methodology (Intercontinental Exchange). This thesis does not evaluate this new methodology and does not consider what changes the methodology might have on LIBOR, legacy contracts, or the regressions that were performed with SOFR, U.S. EFFR, AA Financial CP, or U.S. CMT rates.
- This thesis does not identify or evaluate the risks that are intrinsically associated with each interest rate, including market liquidity risk, counterparty risk (i.e. credit risk premium), term risk, people-related risks, and other operational risks. Each of the rates discussed in this thesis can be evaluated for these risks in order to better understand this thesis' statistical analyses and conclusions.
- Further analysis can be done on LIBOR and other interest rates. This thesis only discusses what rates might be good replacements for U.S. LIBOR, but there could be greater research done for LIBOR denominated in Japanese Yen, etc. There could, additionally, be analysis done around if Eurodollar Futures could be restructured to be an acceptable replacement for LIBOR.
- Additional studies can be performed on historical LIBOR scandal litigations to further determine (i) what and how many banks were involved in manipulation LIBOR in each scandal, (ii) what the courts' decisions were in relation to each scandal, and (iii) the changes in LIBOR's standard deviation before and after the litigation scandals were started and

concluded. Such a study could provide additional statistical evidence for historical LIBOR manipulation.

- This thesis briefly looks into whether there was a recessionary impact on LIBOR and its relation with other interest rates. A much deeper dive could be done into how recessionary periods affect LIBOR and its relationship with other interest rates like U.S. EFFR.

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APPENDIX II: REGRESSION OUTPUTS

The below regression sets are summary outputs of sixty regressions that were performed and used throughout the thesis. To note, any p-values that are below approximately 10^{-250} are rounded to "0" due to the limitations of the statistical analysis programs that were used in the creation of these regressions.

Regression Set #1: United States Secured Overnight Financing Rate

Overnight SOFR on overnight U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			95.97%	Multiple R			99.93%
R Square			92.10%	R Square			99.86%
Adjusted R Square			92.06%	Adjusted R Square			99.44%
Standard Error			7.00%	Standard Error			7.61%
Observations			234	Observations			234
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.23199	6.589	2.9407E-10	**No Intercept**	*N/A*	*N/A*	*N/A*
Overnight SOFR	0.87465	52.000	7.457E-130	**Overnight SOFR**	0.98454	414.481	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			36.56%	Multiple R			36.90%
R Square			13.37%	R Square			13.62%
Adjusted R Square			12.99%	Adjusted R Square			13.19%
Standard Error			1.26%	Standard Error			1.27%
Observations			233	Observations			233
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00127	1.534	0.12635289	**Intercept**	*N/A*	*N/A*	*N/A*
Overnight SOFR	0.17470	5.970	8.8827E-09	**Overnight SOFR**	0.17722	6.048	5.8354E-09

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			0.47%	Multiple R			1.09%
R Square			0.00%	R Square			0.01%
Adjusted R Square			(0.43%)	Adjusted R Square			(0.42%)
Standard Error			1.36%	Standard Error			1.37%
Observations			232	Observations			232
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00155	1.728	0.08529824	**Intercept**	*N/A*	*N/A*	*N/A*
Overnight SOFR	0.00223	0.071	0.94366159	**Overnight SOFR**	0.00522	0.165	0.86902886

Regression Set #2: United States Secured Overnight Financing Rate

1-Month SOFR Futures Contract Rate on 1-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			1.74%	Multiple R			99.86%
R Square			0.03%	R Square			99.72%
Adjusted R Square			(0.73%)	Adjusted R Square			98.97%
Standard Error			12.46%	Standard Error			12.58%
Observations			134	Observations			134
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	2.15016	1.870	0.06376852	**No Intercept**	*N/A*	*N/A*	*N/A*
1-Mo. SOFR Futures	0.09324	0.200	0.84216562	**1-Mo. SOFR Futures**	0.96690	219.029	5.119E-172

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			5.21%	Multiple R			7.80%
R Square			0.27%	R Square			0.61%
Adjusted R Square			(0.49%)	Adjusted R Square			(0.15%)
Standard Error			0.35%	Standard Error			0.37%
Observations			133	Observations			133
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00120	3.930	0.00013661	**Intercept**	*N/A*	*N/A*	*N/A*
1-Mo. SOFR Futures	0.05159	0.597	0.55126569	**1-Mo. SOFR Futures**	0.08148	0.899	0.37018174

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			8.97%	Multiple R			11.26%
R Square			0.81%	R Square			1.27%
Adjusted R Square			0.04%	Adjusted R Square			0.50%
Standard Error			0.35%	Standard Error			0.37%
Observations			132	Observations			132
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00117	3.833	0.00019615	**Intercept**	*N/A*	*N/A*	*N/A*
1-Mo. SOFR Futures	0.08873	1.027	0.30620717	**1-Mo. SOFR Futures**	0.11728	1.297	0.19699424

Regression Set #3: United States Secured Overnight Financing Rate

3-Month SOFR Futures Contract Rate on 3-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			11.30%	Multiple R			99.67%
R Square			1.28%	R Square			99.34%
Adjusted R Square			0.81%	Adjusted R Square			98.87%
Standard Error			18.39%	Standard Error			20.54%
Observations			215	Observations			215
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	3.23867	7.333	4.6378E-12	**No Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. SOFR Futures	(0.29396)	(1.660)	0.09845719	**3-Mo. SOFR Futures**	1.00431	178.806	5.918E-235

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			10.87%	Multiple R			10.74%
R Square			1.18%	R Square			1.15%
Adjusted R Square			0.72%	Adjusted R Square			0.68%
Standard Error			0.37%	Standard Error			0.38%
Observations			214	Observations			214
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00049	1.910	0.05750499	**Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. SOFR Futures	0.04638	1.593	0.11269797	**3-Mo. SOFR Futures**	0.04620	1.577	0.11628075

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			11.78%	Multiple R			11.63%
R Square			1.39%	R Square			1.35%
Adjusted R Square			0.92%	Adjusted R Square			0.88%
Standard Error			0.37%	Standard Error			0.37%
Observations			213	Observations			213
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00052	2.058	0.04077382	**Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. SOFR Futures	0.04977	1.723	0.08633103	**3-Mo. SOFR Futures**	0.04961	1.705	0.08970077

Regression Set #4: United States Effective Federal Funds Rate

Overnight EFFR on overnight U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			99.96%	Multiple R			99.98%
R Square			99.93%	R Square			99.96%
Adjusted R Square			99.93%	Adjusted R Square			99.88%
Standard Error			2.03%	Standard Error			2.17%
Observations			1,229	Observations			1,229
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.01103	13.097	8.829E-37	**No Intercept**	*N/A*	*N/A*	*N/A*
Overnight EFFR	0.99763	1,282.901	0	**Overnight EFFR**	1.00503	1,762.322	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			58.93%	Multiple R			59.14%
R Square			34.73%	R Square			34.98%
Adjusted R Square			34.68%	Adjusted R Square			34.90%
Standard Error			4.00%	Standard Error			4.00%
Observations			1,228	Observations			1,228
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00141	1.231	0.21854477	**Intercept**	*N/A*	*N/A*	*N/A*
Overnight EFFR	0.24877	25.543	9.845E-116	**Overnight EFFR**	0.24963	25.691	7.897E-117

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			6.50%	Multiple R			5.96%
R Square			0.42%	R Square			0.36%
Adjusted R Square			0.34%	Adjusted R Square			0.27%
Standard Error			4.95%	Standard Error			4.96%
Observations			1,227	Observations			1,227
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00372	2.627	0.00873393	**Intercept**	*N/A*	*N/A*	*N/A*
Overnight EFFR	(0.02742)	(2.278)	0.02287759	**Overnight EFFR**	(0.02516)	(2.091)	0.03676171

Regression Set #5: United States Effective Federal Funds Rate

1-Month Federal Funds Futures Contract Rate on 1-month U.S. LIBOR

Regression Output Summary							
Levels on Levels Regression							
Intercept Regression				**No-Constant Regression**			
Multiple R			92.28%	Multiple R			97.74%
R Square			85.16%	R Square			95.53%
Adjusted R Square			85.14%	Adjusted R Square			95.39%
Standard Error			26.43%	Standard Error			32.81%
Observations			714	Observations			714
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	(0.66049)	(19.672)	3.8988E-69	**No Intercept**	*N/A*	*N/A*	*N/A*
1-Mo Fed Funds Futures	1.11937	63.928	3.227E-297	**1-Mo Fed Funds Futures**	0.79020	123.389	0
Daily Percent Change Regressions							
Intercept Regression				**No-Constant Regression**			
Multiple R			7.65%	Multiple R			9.13%
R Square			0.58%	R Square			0.83%
Adjusted R Square			0.44%	Adjusted R Square			0.69%
Standard Error			0.63%	Standard Error			0.67%
Observations			713	Observations			713
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00244	10.338	1.9579E-23	**Intercept**	*N/A*	*N/A*	*N/A*
1-Mo Fed Funds Futures	0.01867	2.045	0.04121681	**1-Mo Fed Funds Futures**	0.02390	2.447	0.01466163
One-Day Delayed Percent Change Regressions							
Intercept Regression				**No-Constant Regression**			
Multiple R			11.31%	Multiple R			12.54%
R Square			1.28%	R Square			1.57%
Adjusted R Square			1.14%	Adjusted R Square			1.43%
Standard Error			0.63%	Standard Error			0.67%
Observations			712	Observations			712
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00243	10.319	2.347E-23	**Intercept**	*N/A*	*N/A*	*N/A*
1-Mo Fed Funds Futures	0.02762	3.034	0.00249808	**1-Mo Fed Funds Futures**	0.03283	3.371	0.00078941

Regression Set #6: United States Constant Maturity Treasury Rate

1-Month United States Constant Maturity Treasury Rate on 1-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			99.57%	Multiple R			99.00%
R Square			99.13%	R Square			98.01%
Adjusted R Square			99.13%	Adjusted R Square			97.93%
Standard Error			7.26%	Standard Error			16.74%
Observations			1,229	Observations			1,229
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.20188	72.811	0	**No Intercept**	*N/A*	*N/A*	*N/A*
1-Mo. CMT	0.98780	374.956	0	**1-Mo. CMT**	1.11536	245.873	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			2.95%	Multiple R			4.92%
R Square			0.09%	R Square			0.24%
Adjusted R Square			0.01%	Adjusted R Square			0.16%
Standard Error			0.95%	Standard Error			0.97%
Observations			1,228	Observations			1,228
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00227	8.384	1.3899E-16	**Intercept**	*N/A*	*N/A*	*N/A*
1-Mo. CMT	0.00077	1.034	0.30129778	**1-Mo. CMT**	0.00132	1.724	0.0849775

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			2.77%	Multiple R			0.62%
R Square			0.08%	R Square			0.00%
Adjusted R Square			(0.01%)	Adjusted R Square			(0.08%)
Standard Error			0.95%	Standard Error			0.97%
Observations			1,227	Observations			1,227
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00232	8.543	3.8291E-17	**Intercept**	*N/A*	*N/A*	*N/A*
1-Mo. CMT	(0.00072)	(0.969)	0.3328474	**1-Mo. CMT**	(0.00017)	(0.218)	0.82752718

Regression Set #7: United States Constant Maturity Treasury Rate

3-Month United States Constant Maturity Treasury Rate on 3-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			99.14%	Multiple R			98.31%
R Square			98.29%	R Square			96.65%
Adjusted R Square			98.29%	Adjusted R Square			96.57%
Standard Error			10.90%	Standard Error			24.88%
Observations			1,229	Observations			1,229
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.30539	71.877	0	**No Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. CMT	1.00754	265.386	0	**3-Mo. CMT**	1.19343	188.191	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			7.05%	Multiple R			9.15%
R Square			0.50%	R Square			0.84%
Adjusted R Square			0.42%	Adjusted R Square			0.76%
Standard Error			0.72%	Standard Error			0.75%
Observations			1,228	Observations			1,228
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00195	9.400	2.572E-20	**Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. CMT	0.00181	2.473	0.01352748	**3-Mo. CMT**	0.00243	3.218	0.00132617

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			0.67%	Multiple R			3.03%
R Square			0.00%	R Square			0.09%
Adjusted R Square			(0.08%)	Adjusted R Square			0.01%
Standard Error			0.73%	Standard Error			0.75%
Observations			1,227	Observations			1,227
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00199	9.597	4.4255E-21	**Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. CMT	0.00017	0.233	0.8158865	**3-Mo. CMT**	0.00080	1.060	0.28920719

Regression Set #8: United States Constant Maturity Treasury Rate

6-Month United States Constant Maturity Treasury Rate on 6-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			98.30%	Multiple R			97.71%
R Square			96.63%	R Square			95.47%
Adjusted R Square			96.63%	Adjusted R Square			95.39%
Standard Error			15.33%	Standard Error			32.29%
Observations			1,229	Observations			1,229
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.41065	64.966	0	**No Intercept**	*N/A*	*N/A*	*N/A*
6-Mo. CMT	0.97195	187.573	0	**6-Mo. CMT**	1.21503	160.924	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			10.48%	Multiple R			11.98%
R Square			1.10%	R Square			1.44%
Adjusted R Square			1.02%	Adjusted R Square			1.35%
Standard Error			0.66%	Standard Error			0.68%
Observations			1,228	Observations			1,228
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00167	8.874	2.4428E-18	**Intercept**	*N/A*	*N/A*	*N/A*
6-Mo. CMT	0.00786	3.691	0.00023319	**6-Mo. CMT**	0.00925	4.227	2.5485E-05

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			18.74%	Multiple R			19.96%
R Square			3.51%	R Square			3.98%
Adjusted R Square			3.43%	Adjusted R Square			3.90%
Standard Error			0.65%	Standard Error			0.67%
Observations			1,227	Observations			1,227
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00164	8.842	3.2012E-18	**Intercept**	*N/A*	*N/A*	*N/A*
6-Mo. CMT	0.01402	6.679	3.6434E-11	**6-Mo. CMT**	0.01539	7.131	1.6941E-12

Regression Set #9: United States Constant Maturity Treasury Rate

12-Month United States Constant Maturity Treasury Rate on 12-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			98.01%	Multiple R			97.16%
R Square			96.06%	R Square			94.39%
Adjusted R Square			96.06%	Adjusted R Square			94.31%
Standard Error			16.42%	Standard Error			41.69%
Observations			1,228	Observations			1,228
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.59369	81.734	0	**No Intercept**	*N/A*	*N/A*	*N/A*
12-Mo. CMT	0.94236	172.963	0	**12-Mo. CMT**	1.28256	143.720	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			12.06%	Multiple R			13.14%
R Square			1.45%	R Square			1.73%
Adjusted R Square			1.37%	Adjusted R Square			1.64%
Standard Error			0.74%	Standard Error			0.75%
Observations			1,227	Observations			1,227
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00129	6.147	1.0656E-09	**Intercept**	*N/A*	*N/A*	*N/A*
12-Mo. CMT	0.01935	4.252	2.278E-05	**12-Mo. CMT**	0.02137	4.641	3.8479E-06

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			38.84%	Multiple R			39.41%
R Square			15.08%	R Square			15.53%
Adjusted R Square			15.01%	Adjusted R Square			15.45%
Standard Error			0.68%	Standard Error			0.69%
Observations			1,226	Observations			1,226
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00114	5.854	6.1512E-09	**Intercept**	*N/A*	*N/A*	*N/A*
12-Mo. CMT	0.06228	14.744	2.0607E-45	**12-Mo. CMT**	0.06407	15.006	7.4691E-47

Regression Set #10: AA Financial Commercial Paper Rate

3-Month AA Financial Commercial Paper Rate on 3-month U.S. LIBOR

Regression Output Summary

Levels on Levels Regression

Intercept Regression				No-Constant Regression			
Multiple R			99.76%	Multiple R			99.80%
R Square			99.53%	R Square			99.60%
Adjusted R Square			99.53%	Adjusted R Square			99.52%
Standard Error			5.72%	Standard Error			8.52%
Observations			1,216	Observations			1,216
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.09730	38.524	9.134E-213	**No Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. AA Fin. CP	1.01176	506.260	0	**3-Mo. AA Fin. CP**	1.07030	553.447	0

Daily Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			0.50%	Multiple R			2.38%
R Square			0.00%	R Square			0.06%
Adjusted R Square			(0.08%)	Adjusted R Square			(0.03%)
Standard Error			0.73%	Standard Error			0.76%
Observations			1,215	Observations			1,215
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00201	9.562	6.1758E-21	**Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. AA Fin. CP	0.00037	0.173	0.8623617	**3-Mo. AA Fin. CP**	0.00183	0.830	0.40664301

One-Day Delayed Percent Change Regressions

Intercept Regression				No-Constant Regression			
Multiple R			7.90%	Multiple R			3.03%
R Square			0.62%	R Square			0.09%
Adjusted R Square			0.54%	Adjusted R Square			0.01%
Standard Error			0.73%	Standard Error			0.75%
Observations			1,214	Observations			1,227
	Coefficient	T-Statistic	P-Value		Coefficient	T-Statistic	P-Value
Intercept	0.00198	9.426	2.0896E-20	**Intercept**	*N/A*	*N/A*	*N/A*
3-Mo. AA Fin. CP	0.00587	2.759	0.00589208	**3-Mo. AA Fin. CP**	0.00731	3.326	0.00090689

APPENDIX III: ADDITIONAL STATISTICAL TESTS

The below are three additional one-sample variance-comparison tests that were performed for comparison purposes. These one-sample variance-comparison tests were all performed using STATA.

Statistical Test #1: United States Effective Federal Funds Rate

Weekly overnight EFFR from 02/18/11 to 07/20/12 against overnight EFFR from 07/27/12 to 12/27/13

```
Variance ratio test

Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
effraf~r |      75    .0012227    .0000367    .0003178    .0011496    .0012958
effrbe~e |      75      .00108    .0000388    .0003357    .0010028    .0011572
---------+--------------------------------------------------------------------
combined |     150    .0011513    .0000272    .0003335    .0010975    .0012051

    ratio = sd(effrafter) / sd(effrbefore)                        f =   0.8959
Ho: ratio = 1                                    degrees of freedom =   74, 74

    Ha: ratio < 1               Ha: ratio != 1                 Ha: ratio > 1
  Pr(F < f) = 0.3187         2*Pr(F < f) = 0.6374           Pr(F > f) = 0.6813
```

Statistical Test #2: AA Financial Commercial Paper Rate

Weekly 3-month AA Financial CP Rate from 02/18/11 to 07/20/12 against 3-month AA Financial CP Rate from 07/27/12 to 12/27/13

```
Variance ratio test

Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
 cpafter |      75     .000932    .0000376     .000326     .000857     .001007
cpbefore |      75    .0010933    .0000563    .0004878    .0009811    .0012056
---------+--------------------------------------------------------------------
combined |     150    .0010127    .0000344    .0004213    .0009447    .0010806

    ratio = sd(cpafter) / sd(cpbefore)                            f =   0.4466
Ho: ratio = 1                                    degrees of freedom =   74, 74

    Ha: ratio < 1               Ha: ratio != 1                 Ha: ratio > 1
  Pr(F < f) = 0.0003         2*Pr(F < f) = 0.0006           Pr(F > f) = 0.9997
```

Statistical Test #3: United States Constant Maturity Treasury Rate

Weekly 3-month U.S. CMT Rate from 02/18/11 to 07/20/12 against 3-month U.S. CMT Rate from 07/27/12 to 12/27/13

Variance ratio test

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
cmtafter	75	.0006987	.0000332	.0002873	.0006326	.0007648
cmtbef~e	75	.0005613	.000041	.0003552	.0004796	.0006431
combined	150	.00063	.0000269	.0003293	.0005769	.0006831

```
    ratio = sd(cmtafter) / sd(cmtbefore)                          f =   0.6543
Ho: ratio = 1                                    degrees of freedom =   74, 74

    Ha: ratio < 1              Ha: ratio != 1               Ha: ratio > 1
  Pr(F < f) = 0.0350        2*Pr(F < f) = 0.0701           Pr(F > f) = 0.9650
```