Templates for Using SOFR

David Bowman, Senior Associate Director
Board of Governors of the Federal Reserve

This information is provided for illustrative and educational purposes only. The views expressed in this presentation are solely those of the author and do not necessarily represent those of the Federal Reserve, the Alternative Reference Rates Committee or its members or ex officio members.
The Secured Overnight Financing Rate (SOFR)

SOFR has a number of characteristics that LIBOR and other similar rates like LIBOR that are based on wholesale term unsecured funding markets do not:

- It is a rate produced by the Federal Reserve Bank of New York (FRBNY) for the public good;
- It is derived from an active and well-defined market with sufficient depth to make it extraordinarily difficult to ever manipulate or influence;
- It is produced in a transparent, direct manner and is based on observable transactions, rather than being dependent on estimates, like LIBOR, or derived through models; and
- It is derived from a market that was able to weather the global financial crisis and that the ARRC credibly believes will remain active enough in order that it can reliably be produced in a wide range of market conditions.

However, SOFR is also new, and many are unfamiliar with how to use it.
SOFR Publication

SOFR is published on the Federal Reserve Bank of New York’s website (https://apps.newyorkfed.org/markets/autorates/sofr) every U.S business day at approximately 8am EST. FRBNY’s revision policies state that SOFR may be revised up to 2:30pm EST.

SOFR is also available on Bloomberg and Reuters and can additionally be accessed through an API offered by FRBNY (https://www.newyorkfed.org/markets/effr-obfr).

The rate published each day represents the rates on overnight repo transactions that were entered in to the previous business day and that are to be repaid on the current business day. So, for example, on April 16, the rate for transactions entered in to on April 15 would be published.

This is similar to how the effective federal funds rate (EFFR) and risk-free rates (RFRs) in other jurisdictions are published.

<table>
<thead>
<tr>
<th>Table 3: The Publication Timing of the RFRs</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOFR</td>
</tr>
<tr>
<td>SONIA</td>
</tr>
<tr>
<td>TONA</td>
</tr>
<tr>
<td>ESTER</td>
</tr>
<tr>
<td>SARON</td>
</tr>
</tbody>
</table>

SOFR is published on every U.S. business day at approximately 8:00am EST. Because the Fed has the ability to correct and republish this rate until 2:30pm New York City Time each day, users may wish to reference the rate after this time (e.g. 3:00pm).

The SOFR rate published on any day represents the rate on repo transactions entered into on the previous business day and the date associated with each rate reflects the date of the underlying transactions rather than the date of publication.
SOFR Data

- FRBNY, in cooperation with the Office of Financial Research, began publishing SOFR on April 3, 2018.

- Prior to the start of official publication, FRBNY released data from August 2014 to March 2018 representing modeled, pre-production estimates of SOFR that are based on the same basic underlying transaction data and methodology that now underlie the official publication. ([https://www.newyorkfed.org/newsevents/speeches/2017/fro171108](https://www.newyorkfed.org/newsevents/speeches/2017/fro171108))

- FRBNY has also separately released a much longer historical data series based on primary dealers' overnight Treasury repo borrowing activity. ([https://www.newyorkfed.org/markets/opolicy/operating_policy_180309](https://www.newyorkfed.org/markets/opolicy/operating_policy_180309))

- A forthcoming note I have written argues that the historical survey data is an adequate proxy for SOFR for risk modelling or other purposes.
Three Key Basic Choices in Determining How to Use SOFR:

• **Averaging: Compound or Simple**
  Compound averaging is used in OIS swaps and some futures. However, many loan and FRN systems currently use simple averaging, largely because of historical precedent. There is some basis between the two types of averaging, although it is generally small. Use of simple averaging may be an expedient to begin using SOFR, but most ARRC members tend to feel that moving toward compounding over time is sensible since it better interest reflects the time value of money.

• **Payment Notice: In Advance, In Arrears, or Hybrid**
  An *in advance* payment structure based on SOFR would reference an average of the overnight rates observed before the current interest period began, while an *in arrears* structure would reference an average of the rates over current the interest period and would only be fully known at the end of the interest period. An average overnight rate *in arrears* will reflect what actually happens to interest rates over the period and will therefore fully hedge interest rate risk in a way that LIBOR or a SOFR-based forward-looking term rate will not.

• **Underlying Market: SOFR (U.S. Treasury Repo Market) or SOFR Derivatives (SOFR futures or OIS)**
  The U.S. Treasury Repo Market underlying SOFR is already deep and highly liquid. SOFR futures and OIS are growing but still at early stages and are not yet deep or highly liquid enough to produce a robust, IOSCO-compliant rate). Many market participants would prefer term rates based on derivatives, but at the same time, the ARRC and the FSB have warned that people should not simply wait for term rates and that those who are able to move to SOFR should seek to do so if they can.
The Different Potential Versions of SOFR-Based Rates

For derivatives, it is fairly clear that the market will be based on compound SOFR in arrears. For cash products, ARRC Working Groups have so far gravitated toward four basic models of SOFR use:

- **Published Simple or Compound Average of SOFR Set in Advance**
  Should require few or no changes to existing systems to use.

- **Published Forward-Looking Term SOFR set in Advance**
  These rates may not come until 2021, but they should require few or no changes to existing systems to use.

- **Simple Average of SOFR Set in Arrears**
  Would require few or manageable changes to existing systems to use.

- **Compound Average of SOFR Set in Arrears**
  Will require more changes to existing systems to use.
Published SOFR Averages

• The Federal Reserve Bank of New York has indicated that it plans to publish averages of SOFR in the first half of next year.

• Averages of SOFR show very little or no impact from these kinds of temporary, day-to-day volatility that can be seen in overnight SOFR around year/quarter-ends.

• A 3-month average of SOFR is less volatile than 3-month LIBOR, even over the last year end.

• FRBNY has not stated whether it will publish compound or simple averages, but the differences between the two choices would typically be small.

• Further details on the average rates that FRBNY would produce should follow, but from an systems perspective, using these rates in advance would be easily implemented.
Forward-Looking Term Rates

- Federal Reserve staff members are producing “indicative” forward-looking term rates that are not meant to be used in contracts and are not IOSCO compliant, but may help provide a sense as to how the term rates will behave (a link to this data, which are periodically updated, is on the ARRC’s website).

- The forward-looking term rates that the ARRC envisions will effectively be segments of the SOFR OIS curve, and as such should behave much like EFFR OIS rates do today.

- The forward-looking term rates should also be tightly linked to compound averages of SOFR, just as EFFR OIS rates are tightly linked to compound averages of EFFR.
Simple Averages of SOFR in Arrears

Monthly SOFR Futures and a number of SOFR FRNs are based on simple averages of SOFR in Arrears. FRN issuance systems had already been developed for the effective fed funds rate based on simple interest, making it easier for initial SOFR FRNs to use simple interest.

Loan systems that use overnight LIBOR, Prime, or the effective fed funds rate based on simple interest are also already frequently in place if not all that regularly used.
Compound Averages of SOFR in Arrears

Three-month SOFR futures, SOFR OIS, and some recent SOFR FRNs are based on compounded averages of SOFR in Arrears, but in general these systems are not yet in place for cash products.

\[ ISDA's \ Compound \ Interest \ Formula = \left[ \prod_{i=1}^{d_b} \left( 1 + \frac{r_i \times n_i}{N} \right) - 1 \right] \times \frac{N}{d_c} \]

Where
- \( d_b \) = the number of business days in the interest period
- \( d_c \) = the number of calendar days in the interest period
- \( r_i \) = the interest rate applicable on business day \( i \)
- \( n_i \) = the number of calendar days for which rate \( r_i \) applies (on most days, \( n_i \) will be 1, but on a Friday it will generally be 3, and it will also be larger than 1 on the business day before a holiday). This can also be stated as the number of calendar days from and including business day \( i \) to but excluding the following business day.
- \( N \) = the market convention for quoting the number of days in the year (in the United States, the convention is \( N = 360 \))

And \( i \) represents a series of ordinal numbers representing each business day in the period.
## An Example of the ISDA Compound Average Formula

**Compound Interest on a One-Week SOFR Loan of $1 Million Drawn on Jan 7, 2019**

<table>
<thead>
<tr>
<th>Date</th>
<th>SOFR Rate</th>
<th>Days</th>
<th>Effective Rate</th>
<th>Principle</th>
<th>Interest Charge for Next Business Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday, Jan 7, 2019</td>
<td>2.41</td>
<td>1</td>
<td>0.0241/360 = 0.006694%</td>
<td>$1,000,000.00</td>
<td>$66.94</td>
</tr>
<tr>
<td>Tuesday, Jan 8, 2019</td>
<td>2.42</td>
<td>1</td>
<td>0.0242/360 = 0.006722%</td>
<td>$1,000,000.00</td>
<td>$67.23</td>
</tr>
<tr>
<td>Wednesday, Jan 9, 2019</td>
<td>2.45</td>
<td>1</td>
<td>0.0245/360 = 0.006806%</td>
<td>$1,000,000.00</td>
<td>$68.06</td>
</tr>
<tr>
<td>Thursday, Jan 10, 2019</td>
<td>2.43</td>
<td>1</td>
<td>0.0243/360 = 0.006750%</td>
<td>$1,000,000.00</td>
<td>$67.51</td>
</tr>
<tr>
<td>Friday, Jan 11, 2019</td>
<td>2.41</td>
<td>3</td>
<td>3\times0.0241/360 = 0.020083%</td>
<td>$1,000,000.00</td>
<td>$200.89</td>
</tr>
<tr>
<td>Monday, Jan 14, 2019</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>$1,000,000.00</td>
<td>$1,000,470.63</td>
</tr>
</tbody>
</table>

**Annualized Compound Rate of Interest:**

\[
\left\{\left(\frac{360}{7}\right)\left(1 + \frac{0.0241}{360}\right)\left(1 + \frac{0.0242}{360}\right)\left(1 + \frac{0.0245}{360}\right)\left(1 + \frac{0.0243}{360}\right)\left(1 + \frac{3 \times 0.0241}{360}\right) - 1\right\}
\]

\[
= (360/7)\times(0.047064\%) = 2.4204\%
\]
Making Compound Calculations Easier – a SOFR Compound Index

An Index would compound daily SOFR every day, similar to a price-level index. It could serve as a trusted key allowing people to calculate compound averages over any period they wanted. It could be used with a “calculator” front end if desired.

\[
I_0 = 1
\]

\[
I_1 = \left(1 + \frac{r_1 \times n_1}{N}\right)
\]

\[
I_2 = \left(1 + \frac{r_1 \times n_1}{N}\right) \left(1 + \frac{r_2 \times n_2}{N}\right)
\]

\[
I_3 = \left(1 + \frac{r_1 \times n_1}{N}\right) \left(1 + \frac{r_2 \times n_2}{N}\right) \left(1 + \frac{r_3 \times n_3}{N}\right)
\]

\[
\vdots
\]

\[
I_T = \left(1 + \frac{r_1 \times n_1}{N}\right) \left(1 + \frac{r_2 \times n_2}{N}\right) \left(1 + \frac{r_3 \times n_3}{N}\right) \ldots \left(1 + \frac{r_{T-1} \times n_{T-1}}{N}\right) \left(1 + \frac{r_T \times n_T}{N}\right)
\]

Or, recursively \( I_T = I_{T-1} \times \left(1 + \frac{r_T \times n_T}{N}\right) \)

Taking the ratio of two Index values automatically calculates compounded interest over the period between the two dates

\[
\frac{I_{t+n}}{I_t} - 1 = \left(1 + \frac{r_{t+1} \times n_{t+1}}{N}\right) \left(1 + \frac{r_{t+2} \times n_{t+2}}{N}\right) \ldots \left(1 + \frac{r_{t+n} \times n_{t+n}}{N}\right) - 1
\]

\[
= \prod_{i=1}^{n} \left(1 + \frac{r_{t+i} \times n_{t+i}}{N}\right) \cdot 1
\]
Deciding Which Segments to Compound

One issue is whether to compound any margin or to only compound the rate and add margin separately

- Compound both rate and margin:
  \[
  \left[ \prod_{i=1}^{d\hat{b}} \left( 1 + \frac{(r_i + \text{margin}) \times n_i}{N} \right) - 1 \right] \times \frac{N}{d_c}
  \]

  Pros: Economically pure – in theory, both rate and margin should compound
  Cons: Harder to calculate, cannot rely on an Index to compound both rate and margin, will have some basis relative to OIS

- Compound rate but not margin
  \[
  \left[ \prod_{i=1}^{d\hat{b}} \left( 1 + \frac{r_i \times n_i}{N} \right) - 1 \right] \times \frac{N}{d_c} + \text{margin}
  \]

  Pros: Easy to calculate, can rely on an Index to compound the rate, will be fully hedged relative to OIS
  Cons: Not economically pure

ARRC Working Groups have gravitated toward compounding the rate but not margin
Models for Using RFRs in Arrears

The FSB and National Working Groups are looking at several models for using overnight risk-free rates in cash products. There are several different variants of both in Arrears and in Advance conventions, as well as potential hybrid conventions that attempt to bridge the difference between the two by allowing for advance notice while also allowing for complete or almost complete hedging of contemporaneous rate movements.

• **In Arrears**
  - *Plain*: Used averaged rate over current interest period, paid on last day of the period (day $T$)
  - *Payment Delay*: Use averaged rate over current interest period, paid $k$ days after day $T$ (Note: ISDA’s conventions for SOFR swaps use a 1-day payment delay)
  - *Lookback*: Use averaged rate over current interest period lagged $k$ days (a 3-5 day lookback has been used in SONIA FRNs)
  - *Lockout*: Use averaged rate over current period with last $k$ rates set at the rate for day $T-k$ (a 3-5 day lockout has been used in most SOFR FRNs).
### Models for Using SOFR in Arrears

<table>
<thead>
<tr>
<th>Day 1 (First Day of Interest Period)</th>
<th>Day 2</th>
<th>…</th>
<th>Day T-2</th>
<th>Day T-1</th>
<th>Day T (Last Day of Interest Period)</th>
<th>Day T+1 (First Day of Next Period)</th>
<th>Day T+2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOFR for Day 1 Published</strong></td>
<td></td>
<td></td>
<td><strong>SOFR for Day T-3 Published</strong></td>
<td><strong>SOFR for Day T-2 Published</strong></td>
<td><strong>SOFR for Day T-1 Published</strong></td>
<td><strong>SOFR for Date T Published</strong></td>
<td></td>
</tr>
</tbody>
</table>

#### Plain Arrears
- Use SOFR for Day 1
- Use SOFR for Day 2
- …
- Use SOFR for Day T-2
- Use SOFR for Day T-1
- Use SOFR for Day T
- **Payment Due**

#### Arrears with Payment Delay
- Use SOFR for Day 1
- Use SOFR for Day 2
- …
- Use SOFR for Day T-2
- Use SOFR for Day T-1
- Use SOFR for Day T
- **Payment Due**

#### Arrears with 1-Day Lockout
- Use SOFR for Day 1
- Use SOFR for Day 2
- …
- Use SOFR for Day T-2
- **Use SOFR for Day T-1**
- **Use SOFR for Day T-1**
- **Payment Due**

#### Arrears with 1-Day Lookback
- Use SOFR for Day 0
- Use SOFR for Day 1
- …
- Use SOFR for Day T-3
- Use SOFR for Day T-2
- Use SOFR for Day T-1
- **Payment Due**

*OIS generally settle at T+2*
A Few Convention Issues for Lookback Structures

**Convention #1:** A lookback uses the rate from \( k \) days ago to calculate today’s interest owed. For example, in a 2-day lookback, if today were Friday, one would use Wednesday’s rate in calculating today’s interest. A narrow definition might be taken to imply that you should apply Friday’s weighting (\( n_i = 3 \) since Friday covers three calendar days until payment is due) to Wednesday’s rate, but a more sensible reading would be to apply Wednesday’s weighting to Wednesday’s rate, which has been called an “observation shift.”

Lookback (narrowly defined):

\[
\prod_{i=1}^{T} \left( 1 + \frac{r_{T-k} \times N_i}{N} \right) \text{ paid on } T + 1
\]

Lookback with observation period shift:

\[
\prod_{i=1}^{T} \left( 1 + \frac{r_{T-k} \times N_{T-k}}{N} \right) \text{ paid on } T + 1
\]

A lookback/observation shift will be fully hedged relative to OIS while a lookback with no observation shift will have some basis.

**Convention #2:** Is using the SOFR rate published today for the business day’s rate a lookback? The SOFR rate published today represents that market rate for borrowing on the previous business day to be repaid today, and FRBNY post it as the rate for the previous business day. OIS markets would not refer to this as a lookback, and some recent FRNs have taken the same convention, but some of the early FRN issuances did call this a 1-day lookback. The payments and when they are to be made regardless, but potential differences in what constitutes a lookback can cause confusion if not understood.
For Those Who Like Math

Pure Arrears: \[ \prod_{i=1}^{T} \left(1 + \frac{r_i \times n_i}{N}\right) \text{ paid on } T + 1 \]

Payment Delay: \[ \prod_{i=1}^{T} \left(1 + \frac{r_i \times n_i}{N}\right) \text{ paid on } T + k \]

Lookback (narrowly defined): \[ \prod_{i=1}^{T} \left(1 + \frac{r_i - k \times n_i}{N}\right) \text{ paid on } T + 1 \]

Lookback with observation period shift: \[ \prod_{i=1}^{T} \left(1 + \frac{r_i - k \times n_i - k}{N}\right) \text{ paid on } T + 1 \]

Payment Delay with interest period shift: \[ \prod_{i=1}^{T - k} \left(1 + \frac{r_i \times n_i}{N}\right) \text{ paid on } T + 1 \]

Lockout: \[ \prod_{i=1}^{T - k - 1} \left(1 + \frac{r_i \times n_i}{N}\right) \prod_{i=T-k}^{T} \left(1 + \frac{r_{T-k} \times n_i}{N}\right) \text{ paid on } T + 1 \]

For Those Who Like Math
In Arrears: Lockout Versus Lookback

Payment Delays or Lookbacks with observation shift are consistent with ISDA compounding definitions and more easily hedged and does not skip any interest days. A lockout does skip some days and has some basis to the In Arrears model used in OIS swaps (below), On the other hand, for most of the interest period, the daily interest rate will correspond to the most recent published value of the RFR, which may be important to certain investors who do not have hedging needs.

Basis between Quarterly Compounded 3-day Lockout vs Pure Arrears (bp)
Most cash product issuances have used in Arrears frameworks, but there have been a wide array of choices between lookbacks, payment delays, and lockouts as well as compounding versus simple averaging.

<table>
<thead>
<tr>
<th>In Arrears/In Advance</th>
<th>SOFR FRNs</th>
<th>SONIA FRNs</th>
<th>Swiss Working Group FRN Recommendations</th>
<th>OIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averaging</td>
<td>In Arrears</td>
<td>In Arrears</td>
<td>In Arrears</td>
<td>In Arrears</td>
</tr>
<tr>
<td></td>
<td>Generally simple average, but several recent issuances have used compound averages</td>
<td>Compound Average</td>
<td>Compound Average</td>
<td>Compound Average</td>
</tr>
<tr>
<td>Payment Delay</td>
<td>Generally none (Payment due next business day after Accrual Period ends), although one recent issuance employed a payment delay except for the final payment</td>
<td>None (Payment due next business day after Accrual Period ends)</td>
<td>None (Payment due next business day after Accrual Period ends)</td>
<td>One business day (Payment due two business days after accrual period ends)</td>
</tr>
<tr>
<td>Lookback</td>
<td>0-2 business days</td>
<td>5 business days</td>
<td>3-5 business days</td>
<td>None</td>
</tr>
<tr>
<td>Lockout/Suspension Period</td>
<td>Generally 2 business days</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>
In Arrears/In Advance (continued)
The amount of basis between In Advance and In Arrears depends on the frequency of interest periods. With a one-month reset, the basis is comparable to the amount of basis between simple and compound averaging. Even at 3- or 6-month resets the basis is limited and averages out to zero over longer periods of time.

Basis Spread between in Advance and In Arrears 5-Year Loan with Monthly Payments (bp)
Hybrid Models
Hybrid Models mix an in Advance payment structure with in Arrears accrual of principal/interest owed:

Principal Accrual: Payments set *In Advance*, principal and interest accrue *In Arrears*

Interest Rollover: Payments set *In Advance*, any missed interest relative to *In Arrears* is rolled over into the next payment period.

Either of the Hybrid Models can substantially further cut the basis relative to a pure In Arrears baseline, even for a product with a less frequent reset such as 5/1 ARM, while still allowing borrowers to know their payments at the start of the interest period.

![Graph comparing bases to In Arrears for the Hybrid 5/1 Mortgage Models](image-url)

Source: Federal Reserve Bank of New York, Haver; Federal Reserve Board staff calculations
Hybrid Models (cont’d)
These models don’t materially alter the cumulated payments that a borrower would make relative to a basic Last Reset In Advance Product. They could be fairly easy to incorporate into some business loans, and from a systems perspective, all that would be needed is the ability for systems to accrue interest and billing or principal accumulation accordingly.

Source: Federal Reserve Bank of New York, Haver; Federal Reserve Board staff calculations
Questions?