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How the IBOR reform affects interest rate swaps

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No. 232

**How the IBOR Reform Affects
Interest Rate Swaps**

by Josua Goebel, Thomas Heidorn, Zizhen Huang

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Abstract

This paper examines how the IBOR Reform affects interest rate swaps (IRS), focusing on Euro and US Dollar. The effects are derived by (1) studying publications from the standard setting bodies behind the reforms and (2) by analyzing swap conventions and clearing eligibility criteria at LCH, CME, and Eurex. The paper finds a limited impact on Euro IRS, as it has retained its credit-risky and forward-looking benchmark rate in the (hybrid) EURIBOR. The largest adjustment has been the shift from EONIA to €STR OIS discounting. USD IRS will move from USD LIBOR to the overnight rate SOFR. Consequently, interest rates are calculated by compounding the daily SOFR rates over the interest period. As the rate is no longer forward-looking, the floating rate is set at the end of the interest period (“fixed in arrears”). SOFR does not contain a term premium and is nearly risk free unlike USD LIBOR. One direct result is a lower swap rate. Moreover, banks no longer have an interest rate that captures their funding costs. Lastly, EURUSD cross currency swaps now mostly exchange €STR for SOFR instead of EURIBOR for USD LIBOR, which has increased the cross-currency basis.

Key words:

IBOR Reform

LIBOR

SOFR

€STR

EURIBOR

RFRs

Overnight rate

OIS

Compounding in arrears

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Cross currency swaps

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List of Abbreviations

12M	Twelve months
1W	One week
1M	One month
2M	Two months
3M	Three months
6M	Six months
AMERIBOR	American Interbank Offered Rate
ARR	Alternative reference rate
ARRC	Alternative Reference Rates Committee
AXI	Across-the-curve credit spread index
BBA	British Bankers' Association
b	Billion
BIS	Bank for International Settlements
BMR	Euro Benchmarks Regulation
Bps	Basis points
BSBY	Bloomberg Short-Term Bank Yield Index
CCP	Central clearing counterparty
CFTC	Commodity Futures Trading Commission
CHF	Swiss franc
CIP	Covered interest rate parity
CME	Chicago Mercantile Exchange
CRITR	Credit Inclusive Term Rate
CRITS	Credit Inclusive Term Spread
CSA	Credit support annex
DF	Discount Factor
ECB	European Central Bank
EFFR	Effective Federal Funds Rate
EMMI	European Money Markets Institute
EONIA	Euro Overnight Index Average
ESMA	European Securities and Markets Authority
ESTER/€STR	Euro short-term rate
EU	European Union
EUR	Euro
EURIBOR	Euro Interbank Offered Rate
FCA	Financial Conduct Authority
FICC	Fixed Income Clearing Corporation
FRA	Forward Rate Agreement
FRBNY	Federal Reserve Bank of New York
FRN	Floating rate note
FSMA	Financial Services and Markets Authority
FSB	Financial Stability Board
GBP	Pound sterling
GCF	General collateral financing
GFC	Global financial crisis
IBA	ICE Benchmark Administration Limited
IBOR	Interbank offered rate

ICE	Intercontinental exchange
IRS	Interest rate swap
ISDA	International Swaps and Derivatives Association
JPY	Japanese yen
LCH	London Clearing House
LIAR	Libor in arrears
LIBOR	London interbank offered rate
m	Million
MMF	Money market fund
MMSR	Money Market Statistical Reporting
MRAC	Market Risk Advisory Committee
NPV	Net present value
OBFR	Overnight Bank Funding Rate
OIS	Overnight indexed swap
ON	Overnight
OTC	Over-the-counter (not exchange traded)
PAI	Price Alignment Amount or Price Alignment Interest
PV	Present value
PV01	Present value of a basis point
Repo	Repurchase agreement
RFR	Risk-free rate
SOFR	Secured Overnight Financing Rate
t	Trillion
USD	US Dollars
vs	Versus

1. Introduction

Interbank Offered Rates, or IBORs, were the interest rates at which banks could obtain funding by borrowing from one another for different tenors, ranging from overnight to 12 months. IBORs are far more than simply an indicator of bank funding costs. IBORs serve as the primary benchmark interest rates for financial markets and products. In total, the payments of financial instruments worth hundreds of trillions¹ are tied to an IBOR. Additionally, discount rates are commonly calculated from IBORs, thereby affecting market participants without any direct IBOR exposure. In short, IBORs are vital for our financial system and affect a wide array of market participants.

An interest rate swap (IRS) is a derivative contract in which two parties exchange interest rates. The most common type of IRS is a fixed vs. float swap, in which one party pays a fixed interest rate and receives a floating interest rate. The interest rates exchanged in swap agreements are commonly indexed to some interbank rate. According to the Bank for International Settlements (BIS), interest rate swaps account for approximately 61% of the notional and 64% of the market value of all OTC derivative contracts as of H1 2021.²

Undoubtedly, IBORs and interest rate swaps are at the heart of financial markets. Since the start of 2022, however, most IBORs have either been reformed, are no longer published, or have been replaced by new reference rates as outlined by the IBOR Reform. The new reference interest rates, so-called RFRs (risk-free rates), reflect the cost of borrowing money overnight for bank and non-bank counterparties. This paper aims to explore how the reforms of IBORs and how the fundamental change in reference interest rates, from IBORs to RFRs, affect interest rate swaps. This exploration is a necessity, as evidenced by trillions of USD in interest rate swaps outstanding, and due to the recency of the IBOR Reform, which is still ongoing in some currency jurisdictions.

This paper is structured into two parts. After some background introduction, which outlines the reforms for Euro and US Dollar benchmark rates, the first part compares the new RFRs to the old IBORs alongside dimensions such as fixing conventions and credit risk. The second part draws on this comparison to assess how the IBOR Reform affects interest rate swaps, including cross currency swaps.

2. Literature Review

Extensive research has already been conducted discussing the flaws with IBORs and why they had to be reformed, for example by the Financial Stability Board (2014) and by Duffie and Stein (2015), hence the backdrop to the reforms is only very briefly discussed. Studies looking at the benchmark reforms themselves are less numerous. Heidorn and Schaefer (2020), for example, provide a detailed summary of the Euro benchmark reforms. This paper builds on their work and complements it with the latest publications by the European Central Bank

¹ \$223t USD LIBOR exposure (ARRC, 2021c, p. 9) and \$180t EURIBOR exposure according to the European Commission, 2016

² See appendix A

(ECB), European Money Markets Institute (EMMI), and the Euro Working Group for Risk-Free Rates. For the USD benchmark reforms, the paper primarily relies on work by the Alternative Reference Rates Committee (ARRC) and the Federal Reserve Bank of New York (FRBNY). Positively, this literature is very recent and comes directly from the standard setting bodies responsible for the IBOR Reform, overseeing the transition, and administering the new benchmark rates. A limitation of these sources is that they closely follow the view of the regulators (rate publishers), instead of market participants (rate users), who might be more critical of the reforms.

Part one, which compares RFRs and IBORs, can draw on some existing literature. Schrimpf and Sushko (2019) and Klingler and Syrtstad (2021) outline features of the new RFRs, compare them to existing benchmarks, and examine what drives RFRs. There is a clear research gap, however, when it comes to taking these findings and assessing their actual implications for financial products such as interest rate swaps. This is where part two of this paper comes in. As academic sources are virtually non-existent at the time of writing, for part two the paper uses information from institutions closely intertwined and involved with financial markets, such as Bloomberg, London Clearing House (LCH), and the International Swaps and Derivatives Association (ISDA).

3. IBOR Reform

IBORs serve as benchmark interest rates. This means that they are referenced and used by many different parties across the economy and financial markets in particular. They are calculated by an independent body, regularly updated, and publicly accessible. As the European Central Bank (2019b) explains, their usefulness derives from the fact that they offer a “reliable, independent, and relatively simple reference” which “creates transparency for all parties involved, brings some standardization to the agreement and, as a result, makes it easier for all parties to negotiate”.

To exemplify how IBORs are measured and published, it is worthwhile to look at the most widely used and well-known IBOR, the London interbank offered rate, or LIBOR. It is administered by ICE Benchmark Administration Limited (IBA)³, which sends the following daily question to a panel of banks: “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 11:00 London time?” (Intercontinental Exchange [ICE], 2022). Panel banks submit quotes for five currencies (USD, EUR, JPY, GBP, and CHF) and for seven tenors for each currency (overnight, one week, one month, two months, three months, six months, and 12 months). According to the IBA, “the panel bank methodology is designed to produce an average rate that is representative of the rates at which large, leading, internationally active banks with access to the wholesale, unsecured funding markets could fund themselves in that market in particular currencies for certain tenors.” (ICE, 2022).

The IBORs had to be reformed for numerous reasons. During the global financial crisis (GFC) the interbank markets, on which quotes were based, dried up. After the GFC, the inter-

³ LIBOR used to be published by the British Bankers’ Association (BBA) until 2014

bank markets did not recover. One reason is the loose monetary policy of many central banks in recent years, culminating in banks holding ample liquidity in the form of central bank reserves and lessening the need for market-based funding. Furthermore, new regulatory requirements since the global financial crisis have made lending and borrowing in the unsecured interbank market less attractive. Additionally, the LIBOR scandal in 2012 revealed that banks had been manipulating their LIBOR submissions. As the value of many interest rate derivatives is contingent on LIBOR, trading desks would collude to try to influence the LIBOR fixings to increase their profits. Using Barclays in 2007 as an example, even a relatively small move in the value of LIBOR would have led to daily value changes of £20m (\$40m at the time) (The Economist, 2012). Besides trying to move LIBOR to the benefit of the own derivatives position, banks also misrepresented their financial health by deliberately underestimating their funding costs (Duffie and Stein, 2015, p. 196). In the end, banks ended up paying fines totaling more than \$10b for their rate rigging (Wingenbach, 2021).

The manipulation scandal revealed multiple design flaws in the way the LIBOR rates are fixed. Firstly, the LIBOR submissions made by the panel banks do not rely on actual transactions but on expert judgement. For example, what constitutes a “reasonable” market size? Instead of asking banks for the rates at which they had actually borrowed, banks were asked for the rates at which they could borrow (Held, 2019). Secondly, the banks making submissions have an inherent conflict of interest, because the value of their own derivative positions depends on LIBOR. On a related note, banks do naturally not want to signal their own declining creditworthiness by submitting LIBOR quotes showing their rising funding costs.

The manipulation scandal spotlighted the fact that trillions of USD were tied to a benchmark interest rate derived from a relatively inactive and manipulation-prone market. Banks became reluctant to submit LIBOR quotes, due to the high litigation risks and lack of an active market against which to validate their quotes. In 2017, the head of the Financial Conduct Authority (FCA), Andrew Bailey, warned that the FCA could not guarantee that panel banks would still submit LIBOR quotes after 2021, thereby putting a deadline on LIBOR.

In 2014, the G20 tasked the Financial Stability Board (FSB) with reviewing major interest rate benchmarks, and with planning and coordinating a reform. The FSB set forth the following two general principles that interest rate benchmarks should fulfill. One, the benchmark rates should be anchored in observable transactions wherever possible. Two, alternative risk-free benchmark rates (RFRs) should be developed (FSB, 2014, pp. 1-5).

For the Euro, the two most prominent benchmark interest rates pre-reform were EURIBOR (euro interbank offered rate) and EONIA (euro overnight index average). Their reform was driven by the EU Benchmarks Regulation (BMR), which essentially made the FSB guidelines legally binding. Systematically important benchmarks now had to satisfy certain standards and comply with the BMR, otherwise they could not be used in new contracts after 1 January 2022 (European Union, 2016). On 28 June 2017, EURIBOR and EONIA were added to the list of systematically important benchmarks (European Union, 2017).

As a result of the reforms, the calculation methodology behind EURIBOR (now called Hybrid EURIBOR) has changed. Firstly, its scope was extended beyond the interbank market to include transactions of panel banks with non-bank counterparties such as money market funds

and insurance companies. Secondly, it is now based both on actual transactions and expert opinion. It uses a waterfall methodology with a hierarchy of levels. Level 1 inputs are actual transactions executed T-1 before publication on T with a minimum volume of €20m. Level 2 quotes are interpolated, for example from transactions from adjacent tenors or from prior dates. Alternatively, the submission can be based on data from other markets, such as futures contracts referencing EURIBOR. These submissions would be categorized as level 3 and are essentially expert opinion based. While the Hybrid EURIBOR is now BMR conforming, most quotes are still based on expert opinion and panel banks are not obliged to make submissions indefinitely. This poses the risk of discontinuation for the EURIBOR.

Pre-reform, the Euro's risk-free rate was EONIA (euro overnight index average). The methodology behind EONIA was to be overhauled to make it eligible under the new benchmark regulation. Positively, EONIA was already anchored in observable transactions, the highest priority of input data under the BMR. However, an inquiry revealed an insufficient number of transactions and a highly concentrated market (Heidorn and Schaefer, 2020, p. 7). Therefore in 2018, its administrator deemed EONIA as non-compliant with the BMR and could not guarantee its publication indefinitely. The alternative risk-free rate recommended was €STR, the euro short-term rate (ECB, 2019a, pp. 6-11). €STR measures unsecured overnight borrowing costs of euro area banks. Specifically, €STR is calculated from "overnight unsecured fixed rate deposits transactions over €1m" (ECB, 2021, p. 2). These transactions from the unsecured market segment are reported by 47 banks and collected by the Money Market Statistical Reporting (MMSR). The rate published is based on transactions from the previous day, including transactions with bank and non-bank counterparties.

The prominent US Dollar benchmark interest rate was USD LIBOR. The Federal Reserve formed the Alternative Reference Rates Committee (ARRC) on 17 November 2014 in response to the Financial Stability Board's review of major interest rate benchmarks. The ARRC was tasked with identifying alternative reference interest rates to USD LIBOR that follow the FSB's principles. The ARRC recommended the Secured Overnight Financing Rate (SOFR) in June 2017. SOFR uses transactions from the US Treasury repo markets, which play a crucial role for matching lenders and borrowers of cash in USD markets (ARRC, 2018, p. 7). SOFR is a "broad measure of the cost of borrowing cash overnight collateralized by Treasury securities" (FRBNY, 2022b). The ARRC views overnight rates as the only viable alternative to LIBOR, because only overnight markets are deep enough to support the amount of business linked to USD LIBOR. The future course of LIBOR became clear on 5 March 2021, when the Financial Conduct Authority and ICE Benchmark Administration clarified when LIBOR panels will end. USD LIBOR for tenors of one week and two months USD will cease after 31 December 2021, and the remaining tenors after 30 June 2023. Regulators mandated that no new contracts be created after 2021 that reference USD LIBOR (ARRC, 2021d, p. 2). This means for the US Dollar there will be no comparable IBOR once USD LIBOR ceases after 30 June 2023. The ARRC recommends replacing USD LIBOR with SOFR, the RFR for the US Dollar, in new contracts and in existing contracts as fallback. So as opposed to the Euro, at the time of writing it looks like there will be no unsecured term lending rate like LIBOR available for the USD after 30 June 2023, and most contracts will be indexed to the RFR, SOFR.

4. IBORs versus RFRs

While the previous chapter summarized the benchmark reforms for the Euro and the US Dollar, this chapter showcases the fundamental differences between the old IBORs and the new (nearly) risk-free overnight rates (RFRs). Before, the features of the new rates were detailed. Now, the impacts of these features and the impacts from the transition from IBORs to RFRs are explored in depth. As Klingler and Syrstad (2021, p. 784) put it, “given that spread changes of a few basis points can translate to valuation changes of millions of dollars, a deeper understanding of the drivers behind these alternative benchmarks is crucial”.

4.1 The Drivers of Risk-Free Rates (RFRs)

The IBOR transition entails a shift to overnight rates. A typical transaction in the overnight market could be a bank that at the end of the day either has a surplus or deficit of funds that it would respectively intermediate or close. Thus, in contrast to term rates like LIBOR, which entails funding of up to twelve months, overnight rates are more like a short-term liquidity indication. This “I need cash now” market dynamic is therefore largely driven by the overall liquidity in markets and thus ultimately by central bank policies. Since the global financial crisis and especially since the Covid-19 pandemic, financial markets have been flush with liquidity from central banks, which has been reflected in low overnight rates. Asset purchase tapering and policy rate hikes in the face of rising inflation would pull liquidity out of the financial system, which could increase overnight rate volatility and lead to spikes.

Klingler and Syrstad (2021) examined how the new RFRs behave under different liquidity scenarios and which factors cause upward or downward spikes. They found that if banks only hold few reserves, a further drop in reserves increases banks’ borrowing and subsequently interest rates. Next, they examined the effect of regulatory constraints, which differs between SOFR and €STR. If banks hold ample reserves and regulations tighten, demand for borrowing is reduced and €STR decreases. Conversely for SOFR, reserves are more concentrated at a few large banks and bank to non-bank lending transactions are included in the calculation of the rate. A stricter regulatory environment makes these banks more reluctant to lend out cash, so SOFR increases. The authors found that since reporting of leverage ratios started in January 2013 in the US, SOFR has on average been 20.25 basis points higher at quarter-ends. Lastly, Klingler and Syrstad (2021) observed that increases in government debt lead to an increase in the RFRs. Investors will prefer to invest in government debt, for example US Treasuries, instead of lending to banks (crowding-out effect). This effect is amplified for SOFR, which is collateralized by US Treasuries. An increase in Treasuries will be financed by dealers through the repo market, increasing collateralized borrowing and ultimately SOFR.

The new RFRs (overnight rates) are more volatile than IBORs (term rates) on a *day-to-day basis*. Overnight rates can be more volatile because they are, as explained earlier, a short-term liquidity indication. If the banking system desperately needs money, prices can go anywhere, as hinted when SOFR spiked to above 5% in September 2019. However, few if any financial contracts reference a one-day reading of the RFR. Instead, most contracts are indexed to an average of the rate, which are not much affected by daily volatility and are actually less volatile than IBORs. For example, the chart below shows that three-months LIBOR is more volatile than a 90-day average of SOFR.

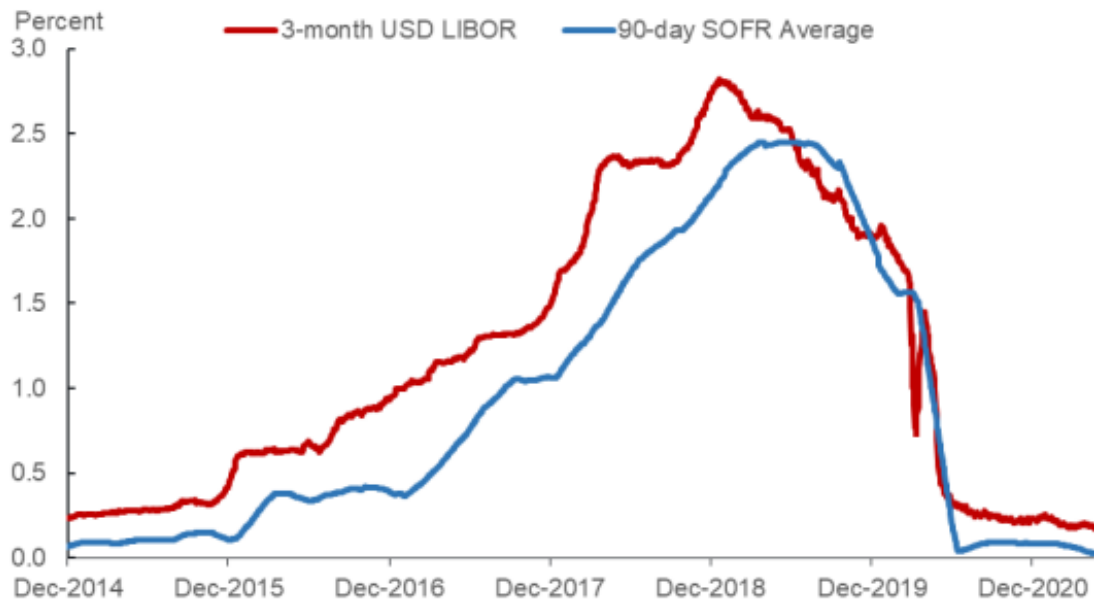


Figure 1: 90-Day SOFR Average versus 3M USD LIBOR (ARRC, 2021c, p. 11)

Even during the September 2019 SOFR spike, the 30-day and 90-day SOFR averages only rose by four and two basis points respectively, as illustrated by the next figure (ARRC FAQ, 2021). Hence, the daily volatility criticisms of RFRs are misplaced.

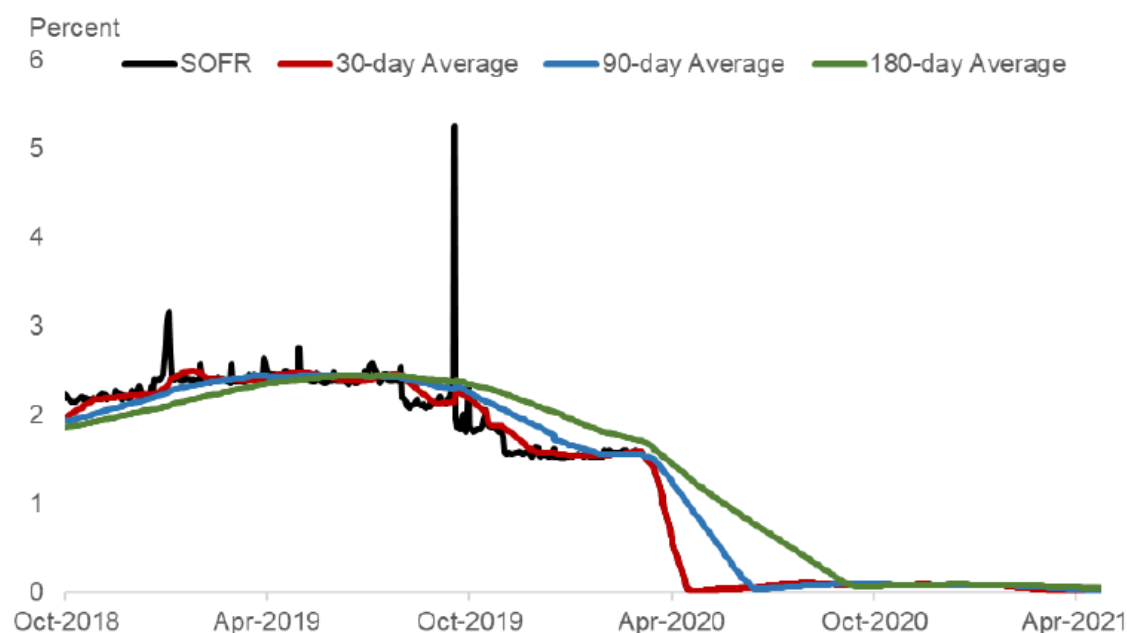


Figure 2: SOFR and SOFR Averages (ARRC, 2021c, p. 11)

Term rates based on overnight rates (RFRs) will also differ from their IBOR counterparts (e.g. EURIBOR and USD LIBOR) in that they do not contain a term premium. The term premium can be decomposed into a liquidity and a credit spread. For a term rate, lenders are committing their capital for a longer time for which they will need compensation. Additionally, the likelihood of default is higher if lending for months instead of only overnight. A term rate based on overnight rates does not contain these premia and is perhaps more comparable to a risk-free term structure. Thus, term rates based on RFRs seem to be more comparable to rates derived from overnight indexed swaps (OIS) than to IBORs (Klingler and Syrstad, 2021, pp. 793-798).

One crucial difference between the old and new interest rates is that the underlying market has been extended beyond interbank to include non-bank counterparties. Therefore, the volume of transactions has increased, volatility is reduced, and the contributions are less concentrated. In the case of €STR, the transaction volume of the top ten banks makes up 85% of the total *interbank* market, which reduces to 70% in the *wholesale* market (Heidorn and Schaefer, 2020, p. 9). This makes the new rates more representative, robust, and less manipulation prone. The higher representativeness also gives the new rates a higher likelihood of automatically capturing changing market structures in the future, for example when transactions underlying the benchmark interest rates shift to different counterparties or instruments. (Heidorn and Schaefer, 2020, p. 9).

Moreover, the scope of borrowings reflected in IBORs has been extended to non-bank counterparties, which do not have access to central bank facilities. Therefore, the interest rates are no longer bound by traditional policy rate boundaries. The ECB's deposit facility, for example, acted as a floor for EONIA, because it did not make sense for banks to invest their funds into deposits yielding a lower rate than they would get at the central bank (Deutsche Bundesbank, 2020b, pp. 56-58).

4.2 Notice of Payment (Fixing)

One of the most fundamental changes in transitioning from IBORs to RFRs are the notice of payment conventions i.e. when the interest rate to be paid is determined ("fixed"). IBORs are typically set in advance, so the floating payment is set and known at the beginning of the interest rate period. This is possible for IBORs since they are forward-looking term rates. RFRs are overnight rates, however, and in the case of SOFR and €STR are published with a one-day delay. Of course, it is hugely impractical to pay the overnight rate daily, so instead the overnight rate is averaged over the interest period and only one payment is made. This means the floating rate to be paid can only be known at the end of the interest period once all overnight rates in that period are known and averaged. Setting the rate at the end of the interest period is known as in arrears. For in arrears fixings, the payment date will usually be set one to two business days after the floating rate for the interest period has been determined, as visualized in the next diagram. This allows the borrower to better prepare for the cash outflow (FSB, 2019, pp. 2-6).

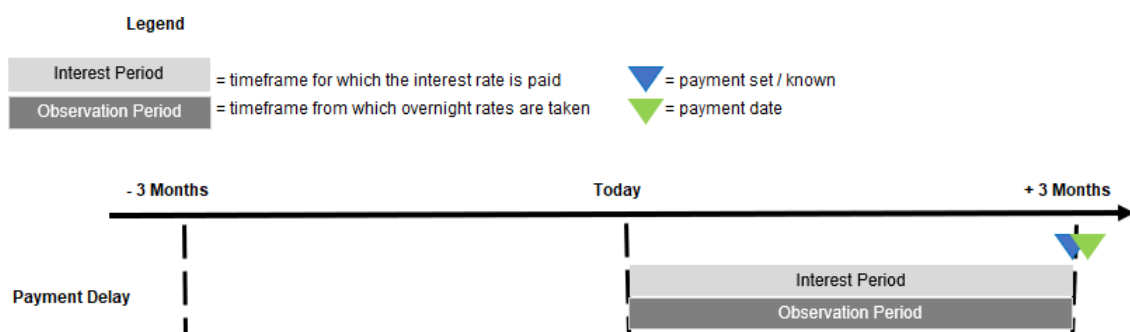


Figure 3: Payment Delay

The in arrears fixing is not unknown to market participants. Overnight indexed swaps (OIS), for which the floating rate is only known at the end of the interest period, have been in use for years. The floating leg in an OIS is tied to an overnight rate, historically EONIA for the Euro or EFFR for the US Dollar. In the mid-90s, some financial products were developed that referenced LIBOR in arrears (LIAR). For LIAR products, the LIBOR rate that would usually have been fixed at the start of the current interest period, was now fixed at the end and used the rate from the next interest period. By paying the LIBOR rate one period earlier than usual, the discounting for this one period is missing. Therefore, a convexity adjustment is needed to

account for this missing discounting (Heidorn and Schmidt, 1998). An overnight rate like SOFR or €STR compounded in arrears reflects the actual movement of rates over a period. Unlike LIAR instruments interest rates are not shifted into “unnatural” periods if the observation period reflects the interest period, so no convexity adjustment is needed. The only similarity between LIBOR in arrears and RFRs compounded in arrears is that the fixing of the floating payment happens at the end of the interest period.

The sequence of overnight rates over an interest period can be calculated using a simple or a compounded average. The simple average is calculated as the arithmetic mean, so all rates in the interest period are added and divided by the number of days. The compounded average also accounts for interest on accrued interest. Simple interest is operationally easier to calculate but compounded is economically more accurate (ARRC, 2021a, pp. 8-9). The formula used to determine the compounded SOFR average can be found in appendix B. Official averages of €STR and SOFR calculated by the ECB and the FRBNY respectively use compounding. The OIS market likewise uses compounded interest. The emerging market standard as advocated by the respective RFR working groups seems to be the RFR compounded in arrears with a payment delay.

There are more possible in arrears conventions for how averaged overnight rates can be used in cash products. Instead of having a payment delay at the end, the rate for the last days is frozen, allowing the final payment to be known a few days before the end of the interest period. If T is the payment date, for example, the overnight rate for $T-2$ would also be used for $T-1$ and T . This lockout or suspension period convention is shown below. The overnight rates from the observation period are used to calculate the average interest rate to be paid. The interest period is the timeframe for which the interest rate is paid (FSB, 2019, p. 8).



Figure 4: Lockout Period

Another possibility is to move the observation period back k days, which is called “look-back”. A 5-day lookback, for example, would apply the rate from 25 March 2022 for 30 March 2022. A lookback convention could either use the number of business days in the observation period (called “shift”) or the number of business days in the interest period (called “without shift” or “lag”) to calculate the averaged rate. In the example above, the rate from 25 March would be applied for one calendar day in either the lookback shift or lag scenario. If hypothetically 31 March 2022 were a holiday, the rate from 25 March would be applied for

two days under lookback with shift and only for one day under lookback without shift (FSB, 2019, pp. 8-9).

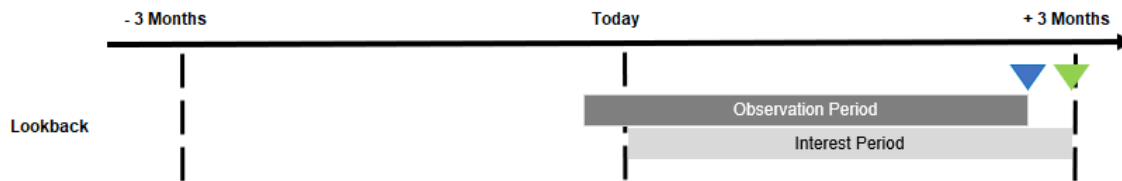


Figure 5: Lookback

It is also possible to apply RFRs in advance. One way is to use the averaged RFRs from the previous period. This “last reset” model ensures payments are known well in advance, but the rate is paid for the “wrong” period. To compensate for the period shift, the rate will have to be adjusted, thereby complicating this fixing convention. Alternatively, an average of overnight rates for only a few days is used for the entire interest rate period (“last recent”). By shortening the observation period, the floating rate to be paid is known early on. However, the resulting interest rate risk profile could not be hedged with existing instruments (FSB, 2019, p. 9). Both the “last reset” and “last recent” notice of payment convention is visualized in the following diagram. For the US Dollar, it is also possible to set the floating rate in advance using term SOFR, calculated by CME using SOFR Futures. Term SOFR is, however, not an average of overnight rates, but like IBORs a forward-looking rate.

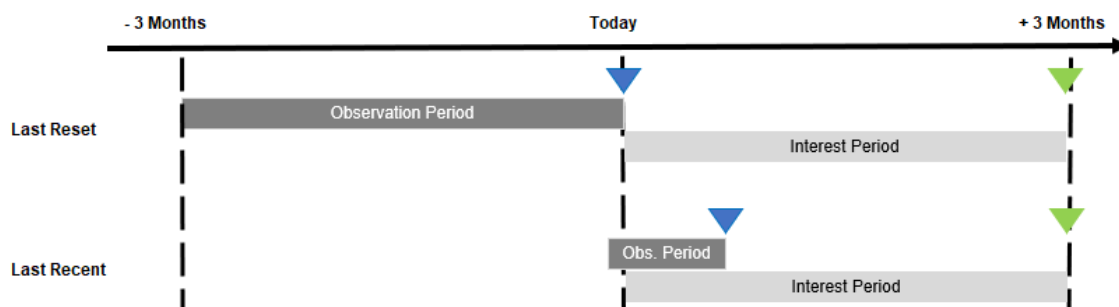


Figure 6: In Advance Fixings

Lastly, hybrid conventions combining elements of both in arrears and in advance conventions have been developed. At the beginning of the interest period, an installment payment is made. At the end of the interest period, the difference between the averaged RFRs for the period and the installment payment is calculated and paid (adjustment payment). The two hybrid conven-

tions illustrated below differ only in the timing of the adjustment payment, which is delayed for the “interest rollover” fixing (FSB, 2019, p. 9).

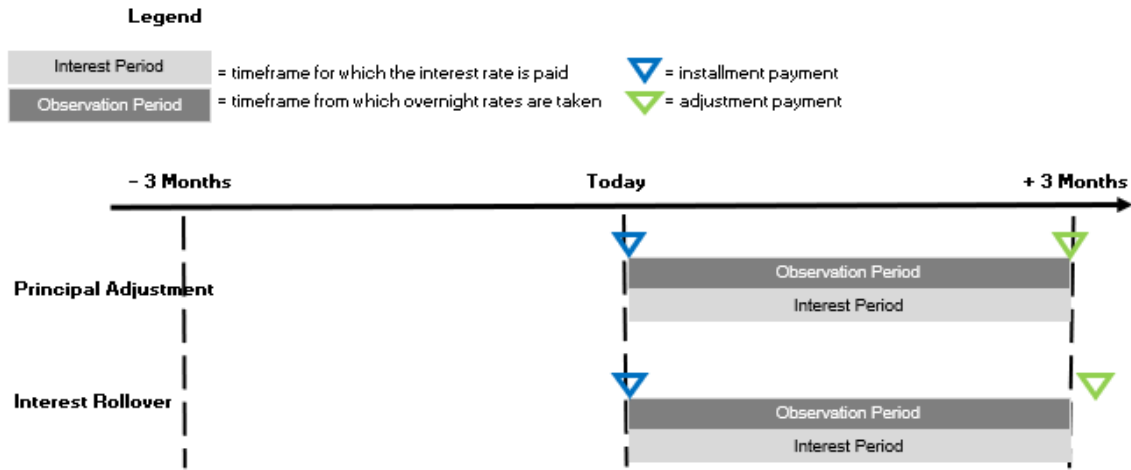


Figure 7: Hybrid Fixings

To conclude, in arrears structures reflect the actual movements of interest rates over a given period, which is desirable for lenders. Borrowers, however, would like to be able to plan their cash outflows as early as possible, which works best with in advance fixings. The hybrid approaches provide ample time to prepare for cash outflows, but still match in arrears returns. In advance fixings have the disadvantage of lagging behind one interest period. The basis caused between overnight rates compounded in advance and in arrears has been quantified and is comparable to the basis involved in LIBOR (ARRC, 2021a, p. 11). The basis between RFRs compounded in advance and in arrears will be higher the steeper the yield curve and the less frequent the interest payments (FSB, 2019, p. 6).

Some hedging basis is also introduced for conventions where the calculated average rate diverges from the actual rate. This is the case for a lockout, for example, for which the rate on the last days is effectively skipped. Furthermore, some in arrears conventions might be problematic for contracts that are callable, allow an early repayment, or that are tradeable with accrued interest. A loan that could be repaid at any time, for example, would not benefit from the advanced notice of payment. A fixing using an observation shift might lead the lender to receive interest for more or fewer days than the principal was lent out for (or pay interest from a borrower’s perspective) when traded or called early. Nonetheless, in arrears is a more effective way to fully hedge interest rate risk compared to in advance. A payment delay may lead

to some cash flow mismatches but could be hedged with SOFR OIS which generally settle T+2 (ARRC, 2021a).

It should be noted that fixing conventions can vary between jurisdiction and between different kinds of cash products, so the conventions presented above may not be exhaustive and may not be the same in different currency jurisdictions. The diagrams were based on the notice of payment visualizations from the FSB’s 2019 paper “Overnight Risk-Free Rates A User’s Guide”. Lastly, these conventions pertain mostly to cash products and should not be expected to be used in interest rate swaps, except for the RFR compounded in arrears with a payment delay, but more on that in chapter five. All introduced notice of payment conventions are summarized in the following diagram.

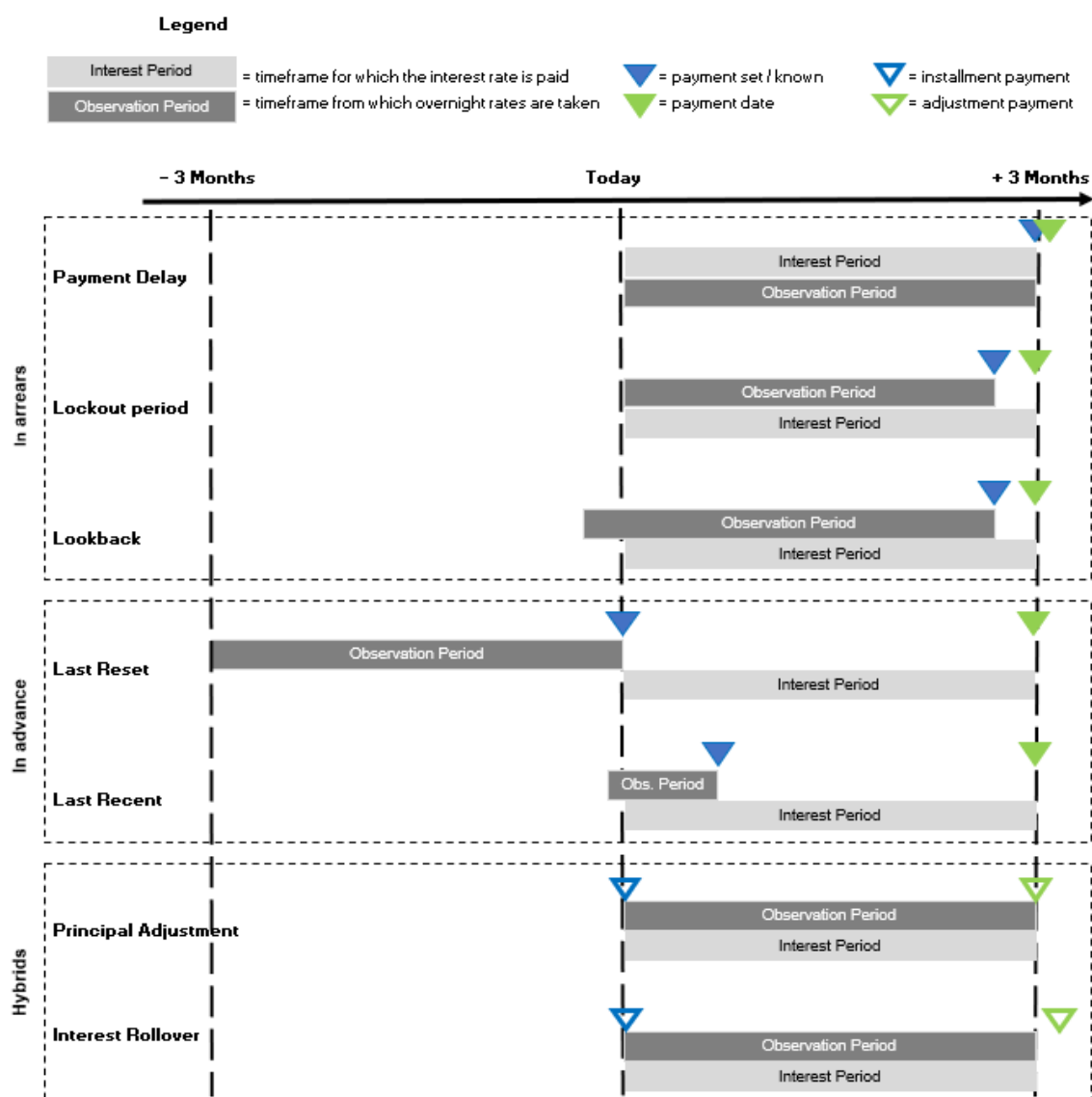


Figure 8: Overview of RFR Fixing Conventions (Visualizations based on FSB, 2019)

4.3 Credit Risk

One crucial difference between USD LIBOR and SOFR is that SOFR is a (nearly) risk-free rate, whereas USD LIBOR contains bank credit risk premia. This means for each tenor, compounded SOFR rates are lower than USD LIBOR. This difference could be approximated by the spreads on basis swaps. Basis swaps are a type of interest rate swap, but as opposed to exchanging a floating and a fixed interest rate, the two parties in a basis swap exchange a floating for a floating interest rate. To make the transaction fair, one party will have to pay a spread on top of the floating rate. The spread captures the difference (basis) between the two different interest rates. In USD LIBOR versus SOFR basis swaps, an unsecured interest rate is exchanged for a secured interest rate and the spread can approximate the difference between the two kinds of rates. This spread cannot exclusively be ascribed to credit risk, but also contains a liquidity and term premium.

Tenor	3M USD LIBOR / SOFR OIS Basis (in bps)
1Y	32.14
2Y	30.47
3Y	29.29
5Y	28.40
10Y	28.36
20Y	28.21
30Y	28.25

Figure 9: 3M USD LIBOR / SOFR OIS Basis (CME, 2022 as of 13 May 2022)

Additionally, the credit spread adjustments on fallback rates could be used to approximate the difference between SOFR and USD LIBOR. When transferring existing USD LIBOR business to SOFR, the credit spread adjustment is supposed to ensure value-neutrality. The credit spread adjustments and how they were derived is detailed in the upcoming chapter 4.4 on fallbacks.

An interest rate benchmark containing bank credit risk is important for a bank's asset-liability management. For example, a bank gives out a fixed-rate loan that it funds by borrowing USD LIBOR. The bank now faces two kinds of risk, one is that the general level of interest rates changes and two that its own credit quality changes. Both lead to a divergence of the rates the bank receives on its asset side and the rates it pays on its liability side. To hedge these risks, the bank will enter into an interest rate swap, in which it swaps the fixed interest from the loan into a floating USD LIBOR payment. In this example a rate like USD LIBOR, which captures the bank's funding costs, ensures that the rates it receives on its asset side behave similarly to

the rates it pays on its liability side. If the interest rate on the loan was tied to SOFR, funding costs would diverge from the interest income from the loan. This divergence is intensified by banks' practice of maturity transformation i.e. borrowing short-term and lending long-term. These new risks and costs could potentially hinder banks' abilities to intermediate funds in an economy and the resulting costs might be passed onto clients (Schrimpf and Sushko, 2019, p. 40).

The fact that SOFR does not contain bank credit risk can become especially problematic for lending products in times of market turmoil, as outlined in a letter from US banks addressed to various US banking regulators (ARRC, 2019). In times of market stress, it is likely that SOFR, which is secured by US Treasury securities, would decrease for two reasons. One, investors would likely increase their investments in US Treasuries, because they are perceived as a safe haven. Two, the Federal Reserve would likely undertake actions intended to ease market participants' access to funding. As a consequence of the decline in SOFR, banks' interest income from SOFR-indexed lending products would decrease. Conversely, LIBOR increases in times of market stress. The decrease in SOFR and increase in LIBOR could be observed at the start of the Covid-19 pandemic (see appendix C) and during the global financial crisis using backward-projected SOFR values (Schrimpf and Sushko, 2019, pp. 45-46). Jermann (2021) estimates that if banks would have held SOFR instead of LIBOR loans during the global financial crisis, they would have missed out on interest between 1% to 2% of the notional amount of outstanding loans, totaling additional interest income as high as \$30b. Besides reducing income on the asset side (loans), a bank's funding costs would increase. Moving from SOFR to LIBOR could therefore remove a natural funding hedge and exacerbate asset-liability mismatches.

Moreover, borrowers tend to hoard liquidity during times of stress and will draw down their existing credit facilities, as observed at the start of the Covid-19 pandemic. If credit facilities are linked to SOFR, their usage becomes even more attractive when SOFR decreases. An additional point to consider is the speed with which unexpected information is reflected in interest rates. If loans reference SOFR compounded in arrears, any changes in rates will be immediately reflected in the daily SOFR rates. For LIBOR-linked products, for which payments are typically set in advance, information is incorporated more slowly. An unexpected rate cut, for example, can only be reflected in the next LIBOR fixing (Jermann, 2021, pp. 6-8). Consequently, banks will either become less willing to lend and/or increase credit spreads on bank lending products to make up for the now missing funding hedge. Even under normal market conditions, banks might curtail lending due to the uncertainty in pricing. In times of market stress, these above-mentioned factors would further strain lenders' liquidity, thereby increasing pro cyclicity (ARRC, 2019). Viewed from a borrower's perspective, the use of SOFR as opposed to LIBOR is favorable. Especially in times of crisis borrowers can benefit from easy and cheap funding. LIBOR's construction exposes borrowers to rising interest costs, just as the market environment turns sour and as observed during the Covid-19 pandemic (Working Group on Sterling Risk-Free Reference Rates, 2020).

A consortium of US banking regulators established credit sensitivity group workshops with market participants to explore the possibility of a credit-sensitive benchmark rate or credit spread add-on to SOFR, but concluded that "the official sector does not plan to convene a group to recommend a specific credit-sensitive supplement or rate..." (FRBNY, 2021). The

credit sensitivity group's workshop from 18 November 2020 featured different methods for incorporating a credit premium. IHS Markit developed the USD Credit Inclusive Term Rate (CRITR) and Spread (CRITS). Berndt, Duffie, and Zhu created an across-the-curve credit spread index (AXI). ICE developed the ICE USD Bank Yield Index. Bloomberg offers the BSBY, the Bloomberg Short-Term Bank Yield Index. All of the rates try to infer unsecured funding costs in a similar way, broadly by using debt issuances like certificates of deposits, commercial papers, and bonds for different tenors. By subtracting the SOFR swap rate for the corresponding tenor, the spread can be backed out. These methods account for credit risk by either constructing a benchmark rate that includes credit risk, or by constructing a credit risk index that can be referenced additionally to SOFR. The American Interbank Offered Rate (AMERIBOR) differs slightly in that it is an overnight rate for smaller US credit institutions and already contains a credit spread component derived from unsecured instruments (FRB-NY, 2020). A credit-sensitive benchmark or index gives market participants the option to choose or construct an interest rate best suited to their specific needs, however it also introduces additional complexity. It stands to be seen if and how credit adjustments for bank lending products referencing SOFR will ultimately be made.

This is currently not of concern for the Euro, as market participants have access to a credit-sensitive benchmark in the Hybrid EURIBOR. For EURIBOR, it may be important to understand how credit risk impacts the rate. The average credit rating was commonly approximated at AA, but since the global financial crisis bank credit ratings have been more dispersed. As a result, EURIBOR might no longer be as accurate a proxy for banks' funding costs. This is of general importance as most credit spreads involving fixed coupons in the market are quoted against the swap curve.

One could argue, however, that these credit-sensitive rates are not as useful anymore as they were before the global financial crisis. After the GFC, bank credit risk became more dispersed, so LIBOR for example, no longer captures any individual bank's credit risk as precisely. Moreover, banks also increasingly borrowed funds from non-bank counterparties, which led to a further divergence in rates. Possibly, the usefulness of benchmark rates like LIBOR after the GFC instead derived from their substantial underlying liquidity, making it relatively easy and cheap to transact in them. This would support the rationale for moving towards RFRs, which had already been in progress for some derivatives anyway (Schrimpf and Sushko, 2019).

When talking about credit risk, it is important to explore how SOFR is impacted by the fact that it is a secured rate. The fact that SOFR is a secured rate collateralized by US Treasury securities means, that the rate is affected by demand and supply forces surrounding US Treasuries. The rate in repurchase agreements is typically driven by the cash-side i.e. the side selling the security in exchange for funds. If more market participants want funds the repurchase rate would increase, all other things held equal. However as mentioned above, in times of market turmoil investors move into safe US Treasuries and the repurchase rate would be driven by the collateral side. An increased demand for US Treasuries lowers the repurchase rate (Schrimpf and Sushko, 2019, p. 39).

The effect of US Treasuries supply and demand forces on SOFR can be seen by comparing the collateralized rate SOFR with the uncollateralized rate EFFR (Effective Federal Funds

Rate). The Effective Federal Funds Rate measures “domestic unsecured borrowings in US dollars by depository institutions from other depository institutions and certain other entities, primarily government-sponsored enterprises” according to the Federal Reserve Bank of New York (2022a). From the end of 2016 to the beginning of 2018, demand for US Treasuries increased as a result of a money market fund (MMF) reform. Thus, market participants were willing to receive a lower rate to receive the desired collateral, thereby pushing SOFR below EFFR. In Q1 2018, the US government began issuing more US Treasury securities. The increased supply in collateral led to an increase in SOFR, as the repurchase rate was now mainly driven by the demand for funds again (Schrimpf and Sushko, 2019, p. 39).

Unconventional monetary policy by central banks, specifically asset purchase programs, could also impact SOFR by changing the amount of liquidity and collateral in the banking system. One possible effect of asset purchase programs could be a reduction in lending and borrowing activities in repo markets, since market participants already have enough liquidity. Alternatively, as the stock of high-quality collateral outstanding is reduced, repo activity could increase due to demand for the scarce collateral. This is not the case in the United States, however, where following asset purchases by the Federal Reserve a decrease in inter-bank trading was observed in the federal funds market, but not in the repo market. It has been observed in US markets that a large amount of excess reserves can put pressure on banks’ balance sheets, which constrains their intermediation capabilities in repo markets and leads to decreasing repo volumes (BIS, 2017, p. 20).

Furthermore, regulatory requirements and taxation impact the repo market and thereby SOFR. At the end of reporting periods, SOFR exhibits greater price and volume volatility because banks are trying to optimize their balance sheets (BIS, 2017, pp. 22-25). An extreme example of reporting period end volatility took place from 16 September to 17 September 2019, when rates jumped from 2.43% to above 5%. Excess reserves decreased significantly because of a tax payment date and increased issuance of US Treasuries, which are financed by dealers through the repo market. Consequently, everyone needed cash (of which there was now less) and no one wanted collateral (of which there was now plenty). A report by the Federal Reserve on the incident thus attributes the spike to a demand-supply mismatch in the market. SOFR had been known to exhibit price spikes at quarter end, but this one was more extreme because reserves had been declining due to the Federal Reserve’s balance sheet normalization. Another market trend, an increased supply of US Treasuries, increased borrowing demand because dealers finance Treasury purchases in the repo market. Once a rate spikes, banks might be reluctant to lend their excess reserves due to heightened uncertainty regarding future market liquidity. As a result, borrowers had to pay a high rate to secure funding (Anbil, Anderson and Senyuz, 2020).

In summary, SOFR and its underlying repo markets are clearly influenced by demand and supply for collateral, namely US Treasuries. Repo market dynamics can be affected by monetary policy and regulatory requirements. It should therefore be noted that future changes in regulations, reporting requirements, and taxation could conceivably impact SOFR. The benchmark interest rates for the Euro are not collateralized, because of the heterogeneity of collateral, so the mechanics of collateralization and repo markets are not relevant here.

4.4 Fallbacks

To further understand the differences between IBORs and RFRs, it could be helpful to examine the fallback conventions in financial contracts. Broadly speaking, fallback conventions are clauses that dictate what happens when a reference interest rate ceases to exist or becomes non-representative. The fallback convention settles what would happen to, for example, an interest rate swap for which the floating leg is indexed to USD LIBOR after 30 June 2023, which is when USD LIBOR is set to discontinue. While EURIBOR is BMR compliant, a future cessation cannot be ruled out. What would happen to contracts referencing EURIBOR in this scenario? Undoubtedly, fallbacks are crucial to financial stability because otherwise the value and interest payments of trillions in contracts could not be calculated in the case of an index cessation. When contracts switch from one interest rate to another, for example from USD LIBOR to SOFR, the value of the contract should in theory not change. Thus, studying how the fallback contract language tries to ensure value neutrality between IBORs and RFRs, can reveal differences between the two.

Generally, fallback clauses are broken down into three distinct parts. The first defines what constitutes an interest rate index cessation event. The second part specifies the fallback interest rate that is to replace the discontinued rate. Third, a spread adjustment for the fallback rate is detailed. The spread adjustment is intended to make the new fallback rate as economically close to the old, ceased rate as possible (value neutrality). Furthermore, fallbacks can be broken down into fallbacks for derivatives and fallbacks for cash products. The fallback language for derivatives is standardized and widely covered by the International Swaps and Derivatives Association fallbacks. The fallback language for cash instruments, however, is substantially more varied and difficult to change ex post (ARRC, 2021e).

What constitutes an Index Cessation Event and the definition of the fallback interest rate is outlined in the ISDA 2020 IBOR Fallbacks Protocol and Supplement. ISDA defines an Index Cessation Event as an announcement by the regulatory supervisor for the rate stating that the rate will cease to be published or is no longer representative of the underlying market (International Swaps and Derivatives Association [ISDA], 2020, p. 50). As written earlier, the index cessation event for LIBOR occurred on 5 March 2021 when the FCA clarified when LIBOR panels will end. At the time of writing, the publication of EURIBOR is not set to discontinue.

The fallback rates for the IBORs are the RFRs in the respective currency plus a spread. For USD LIBOR the fallback rate is SOFR, and for EURIBOR the fallback is €STR.⁴ Bloomberg was selected as the calculation agent for the fallback rate and spread, which is defined in Bloomberg's IBOR Fallback Rate Adjustment Rule Book. The fallback rate is calculated as the RFR compounded in arrears. The spread is fixed on the "Spread Adjustment Fixing Date", which is triggered by an Index Cessation Event, and is calculated as the five-year historical median spread between the RFR and IBOR. The spread adjustments for USD LIBOR have already been fixed on 5 March 2021 and are shown in the table below (Bloomberg, 2021).

⁴ Earlier fallbacks included calling the bank directly for a quote, but this process is highly unlikely to yield a rate in a market stress scenario.

USD LIBOR Tenor	Credit Spread Adjustment (%)
ON	0.00644
1W	0.03839
1M	0.11448
2M	0.18456
3M	0.26161
6M	0.42826
12M	0.71513

Figure 10: USD LIBOR Credit Spread Adjustments (Source: Bloomberg, 2021)

In summary, for derivatives covered by ISDA the fallback rate is the corresponding RFR compounded in arrears plus the five year historical median spread between the RFR and IBOR (Bloomberg, 2020). Unsurprisingly, the spread adjustment is positive. Because the RFRs are overnight rates, the spread is positive to account for the liquidity and credit risk inherent in the IBORs. The fallback rates are different from the IBORs in that the final rate is only known at the end of the interest period. To keep the interest payment date the same, there is a backwards shift of the interest period, visualized earlier as the “lookback” fixing (ISDA, 2021, pp. 2-3).

For cash products, each asset type (e.g. floating rate notes, securitizations, syndicated loans, etc.) in each currency jurisdiction has a specific fallback convention. For USD LIBOR, the ARRC’s recommendations are summarized in “Summary of ARRC’s LIBOR Fallback Language”. The €STR’s working group recommendations can be found in “Euro Recommendations by the working group on euro risk-free rates on EURIBOR fallback trigger events and €STR-based EURIBOR fallback rates”. Like the ISDA fallbacks, the recommendations first define a fallback trigger, before specifying a replacement rate and spread adjustment. The ARRC has chosen Refinitiv as the calculation agent for the spread adjustments for cash products. Additionally, the ARRC has defined a fallback rate and spread waterfall. Without detailing the specific convention for each asset class, it is clear that varying fallback conventions for different cash products increase complexity, especially when hedging these cash products.

Nonetheless, this approach ensures each fallback convention is the best fit for each individual asset class, as opposed to a “one size fits all” approach. The following table summarizes the features of RFRs and their implications as described on the previous pages.

Features	Implications for RFRs
Overnight rate	<ul style="list-style-type: none"> - RFRs depend on short-term liquidity needs in the market - Not forward-looking - Reflect actual movement of rates in period. Do not contain expectation of future rates.
Central Bank Policies	Policies that lead to a drop in reserves increase borrowing and thus rates
Government Policies	Increase in government debt > market participants invest in government debt instead of lending > rates increase, esp. SOFR which is collateralized by government debt
Regulatory Constraints	<p>Tighter regulation (i.e. reporting of leverage ratio)</p> <ul style="list-style-type: none"> - €STR: borrowing is reduced and €STR decreases - SOFR: lending is reduced and SOFR increases
Volatility	<ul style="list-style-type: none"> - Daily volatility is higher than for IBORs, but financial contracts reference averages of RFRs which are less volatile - SOFR spikes quarter-ends (on average 20.25 bps higher)
Term Rate (SOFR)	Does not contain a term premium (liquidity and credit), because it is based on an overnight rate. Can be viewed as risk-free term structure comparable to rates derived from OIS.
Wholesale Market	<p>Moving from interbank to wholesale:</p> <ul style="list-style-type: none"> - volume of underlying transactions increased - volatility reduced - contributors less concentrated - rates more representative - automatically captures changing funding structures - rates no longer bound by central bank facilities
Fixing Conventions	<ul style="list-style-type: none"> - A sequence of daily overnight rates is compounded over the interest period, so the final rate is only known at the end of the interest period (unlike IBORs which are forward-looking). - Generally, a floating payment indexed to €STR or SOFR will be set at the end of the interest period (in arrears), whereas IBORs are set at the beginning (in advance). - Emerging market standard is the RFR compounded in arrears with a payment delay (familiar from OIS). Different in advance, in arrears, and hybrid fixing conventions possible for RFRs.
Credit Risk	<ul style="list-style-type: none"> - RFRs do not contain bank credit risk but are (nearly) risk free. - Complicates banks’ asset-liability management. Rates bank receives on its asset side and pays on its liability side could diverge, especially during market downturns.
Collateralization (SOFR)	<ul style="list-style-type: none"> - SOFR affected by demand and supply for US Treasuries - Repo markets affected by monetary policy and regulatory requirements

Fallbacks	<p>Fallback rate = RFR compounded in arrears + spread adjustment (five-year historical median spread between the RFR and IBOR)</p> <p>When transferring existing IBOR business to RFR, the spread adjustment should ensure value-neutrality. Spread adjustments for USD LIBOR fixed on 5 March 2021.</p>
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Figure 11: Features of RFRs summarized

5. Effects on Interest Rate Swaps (IRS)

Interest rates are crucial for many financial products, and interest rate derivatives make up the largest share of OTC derivatives by far, most of which can be attributed to interest rate swaps. Typically, the floating leg of an interest rate swap is tied to an IBOR. However, as the methodology behind IBORs was changed, this chapter examines how interest rate swaps are affected by these differences.

5.1 Valuation and Usage of IRS (Pre-Reform, Multi Curve)

An interest rate swap is an OTC derivative contract in which two parties agree to exchange (“swap”) interest rates on several future dates. In a plain-vanilla swap, a fixed and a floating interest rate are exchanged (fixed-for-float swap). Payments are calculated by multiplying the corresponding interest rate with the principal (also called notional). Principals are not exchanged (Hull, 2018, pp. 155-158). The fixed rate is called the swap rate. Interest rate swaps are quoted by their fair swap rate, which is the result of supply and demand. Swap rates are the most liquid derivatives market and are commonly used as a benchmark curve themselves. Pre reform, the floating rate was indexed to an IBOR, for example USD LIBOR or EURIBOR.

The initial value of a fair interest rate swap is zero and there is no cashflow. This means the present value (PV) of the cashflows on the fixed leg are equal to the cashflows of the floating leg.

$$PV(\text{fixed leg}) = PV(\text{floating leg})$$

To find the present value, each cashflow has to be discounted. The formula below shows that the present value of the fixed leg is simply the fixed rate (swap rate) in each period (denoted as C) discounted by the respective discount factor (DF).

$$PV(\text{fixed leg}) = C_1 * DF_1 + C_2 * DF_2 + \dots + C_n * DF_n$$

$$PV(\text{fixed leg}) = C * \sum_{i=1}^n DF_i$$

The value of the floating leg is calculated in the same manner, but the rate is not fixed and instead depends on the value of the IBOR it is indexed to. Pre reform, these IBOR values were determined by a panel of banks on the basis of expert judgement and were available at the start of the interest period i.e. the floating rate was fixed in advance. Thus, the first IBOR payment is known today. For the remaining floating IBOR payments forward rates are used. Assuming the floating leg in this example is tied to 12M EURIBOR, f_1 in the formula below would be known and is 12M EURIBOR as of today. f_2 would be the value of 12M EURIBOR in one year from today as implied by forward rates. The value of the floating leg is the sum of discounted forwards.

$$PV(\text{floating leg}) = f_1 * DF_1 + f_2 * DF_2 + \dots + f_n * DF_n$$

$$PV(\text{floating leg}) = \sum_{i=1}^n f_i * DF_i$$

The following formula equates PV(fixed leg) to the PV(floating leg)

$$C * \sum_{i=1}^n DF_i = \sum_{i=1}^n f_i * DF_i$$

which can be rewritten as

$$C = \sum_{i=1}^n f_i * \frac{DF_i}{\sum_{i=1}^n DF_i}$$

The final formula illustrates that the fair swap rate, which makes the contract equal to zero at inception, is equal to the weighted average of the forward IBORs (Schmidt, 2021, pp. 20-23). The fixed rate (swap rate) is the interest rate in exchange for a stream of IBOR payments. Swap rates are quoted versus different IBOR tenors because the swap level depends on the tenor of the floating leg. As the tenor increases, for example from 3M EURIBOR to 6M EURIBOR, the credit risk increases (Schmidt, 2021, pp. 20-34). Consequently, one stream of 6M EURIBOR would be quoted higher than implied by two streams of 3M EURIBOR. The fixed rate (swap rate) is accordingly lower versus 3M EURIBOR than versus 6M EURIBOR.

The discount rates are bootstrapped from overnight indexed swaps (OIS). OIS are swaps for which the floating leg is tied to an overnight rate, which would in the past have been EONIA for the Euro and EFFR for the US Dollar. The floating rate is determined by multiplying the sequence of overnight rates for the given interest period, accounting for interest on interest. Thus, the fixed rate (OIS rate) in an OIS is the return that could be expected over a given interest period if investing at the overnight rate and reinvesting the proceeds each day (Hull, 2018, p. 80). Bootstrapping is a method through which spot rates (and subsequently discount factors) can be determined by iteratively solving a system of equations.

OIS are used to derive discount factors because they reflect the lowest credit risk. After the global financial crisis, central clearing and credit support annexes became common to reduce counterparty credit risk. For both, the IRS are valued daily, and each counterparty has to post collateral to make up for any adverse net present value (NPV) changes. Thus, the risk inherent in these agreements is minimal (Schmidt, 2021, pp. 20-34).

Forwards are bootstrapped using swap rates and discount factors derived from OIS. The graphics below illustrate this process using fictitious market data for a two-year fixed-for-float interest rate swap with a notional of €10m. The two-year swap rate versus 12M EURIBOR would be taken from market quotes and is equal to 2.50%. The fixed rate payer would thus have cash outflows of €250,000 in one and two years from now. These cashflows have to be discounted to today (discount rates would be bootstrapped from EONIA OIS as previously discussed) to arrive at the net present value of the fixed leg. For the floating side, the 12M EURIBOR rate is known today, but the 12M EURIBOR rate in one year from now has to be found (red box with the question mark in the table below).

Notional	10,000,000					
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Fixed Leg

Year	OIS	Spot rate	DF	Swap Rate vs. 12M EURIBOR	Cashflow	NPV
1	1.00%	1.00%	0.9901	2.50%	250,000	247,525
2	2.00%	2.01%	0.9610	2.50%	250,000	240,245

PV(Fixed Leg)	487,769
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Floating Leg

Year	OIS	Spot rate	DF	12M EURIBOR Forward Rates	Cashflow	NPV
1	1.00%	1.00%	0.9901	1.80%	180,000	178,218
2	2.00%	2.01%	0.9610	?	?	?

PV(Floating Leg)	?
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Swap NPV	?
----------	---

(1) OIS, swap rates, and the year 1 forward rate are fictitious
(2) Spot rates are bootstrapped from OIS
(3) $DF = 1/(1 + \text{spot rate})^{\text{year}}$
(4) Cashflow = swap rate or forward rate * notional
(5) NPV = cashflow * DF
(6) PV = sum of NPVs
(7) Swap NPV = sum of PV(fixed leg) and PV(floating leg)

Figure 12: Bootstrapping of Forwards Part 1

As the present value of the floating leg has to equal the present value of the fixed leg, the forward rate for year two is set as to equate both legs. In this example, the 12M EURIBOR forward rate in one year is found to be 3.22% (green box in the table on the next page) and the swap NPV equal to zero.

Notional	10,000,000
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Fixed Leg

Year	OIS	Spot rate	DF	Swap Rate vs. 12M EURIBOR	Cashflow	NPV
1	1.00%	1.00%	0.9901	2.50%	250,000	247,525
2	2.00%	2.01%	0.9610	2.50%	250,000	240,245

PV(Fixed Leg)	487,769
---------------	---------

Floating Leg

Year	OIS	Spot rate	DF	12M EURIBOR Forward Rates	Cashflow	NPV
1	1.00%	1.00%	0.9901	1.80%	180,000	178,218
2	2.00%	2.01%	0.9610	3.22%	322,121	309,552

PV(Floating Leg)	487,769
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Swap NPV	0.00
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Figure 13: Bootstrapping of Forwards Part 2

The forward rate for 12M EURIBOR in two years from now is found through the same process but using a three-year swap. The 12M EURIBOR forward rates today and in one year from now are known. The unknown forward rate in two years for one year is found by equating the present value of the fixed leg to the floating leg and solving for it, and so on.⁵ In essence, forward rates are bootstrapped from fair interest rate swaps. This is swap pricing in a multi-curve setting. Before the global financial crisis, a single-curve setting was used because only the swap curve was needed. From the swap curve, spot rates were bootstrapped and used to calculate the forward rates. This was changed to multi-curve, once discounting shifted to the OIS curve and market participants realized the credit risk was higher for longer IBOR tenors.

5.2 IRS referencing Euro Benchmark Rates

After the swap valuation pre reform has been showcased, the next chapter analysis the impact of the benchmark reforms. For products denominated in Euro mainly the implicit credit risk has changed since the reform. In a fixed-for-float swap, the floating leg would still be indexed to (hybrid) EURIBOR. Hybrid EURIBOR is still a forward-looking unsecured interest rate. The methodology and data behind EURIBOR have changed, for example, it now also reflects wholesale instead of only interbank funding costs and is now partly transaction based. Thus, the underlying market and calculation has been slightly adjusted, but the floating leg of interest rate swaps are still linked to an IBOR as before. As EURIBOR is a forward-looking interest rate, the rate is fixed in advance, usually two days before the start of the interest rate period over which interest is accrued. There is no payment lag.⁶

The rate on the fixed leg is taken from Euro swap curves, so fix versus 1M, 3M, 6M, or 12M EURIBOR, depending on the index of the floating leg. The swap curve is the result of supply and demand. Bids come from market participants that want to enter IRS as the fixed rate receiver, asks from those that will pay a fixed rate in exchange for receiving EURIBOR. The swap curve can be constructed in multiple ways. On the short end, cash or deposit rates are used. Interest rate futures or forward rate agreements (FRAs) are used for the medium-term, and interest rate swaps for the long end (Bloomberg, 2016, pp. 2-4)

⁵ Tables based on FS Derivatives Analysis Workbook (Heidorn, 2021)

⁶ Fixed-for-float interest rate swap set up via Bloomberg Terminal Swap Manager (SWPM) on 25 April 2022

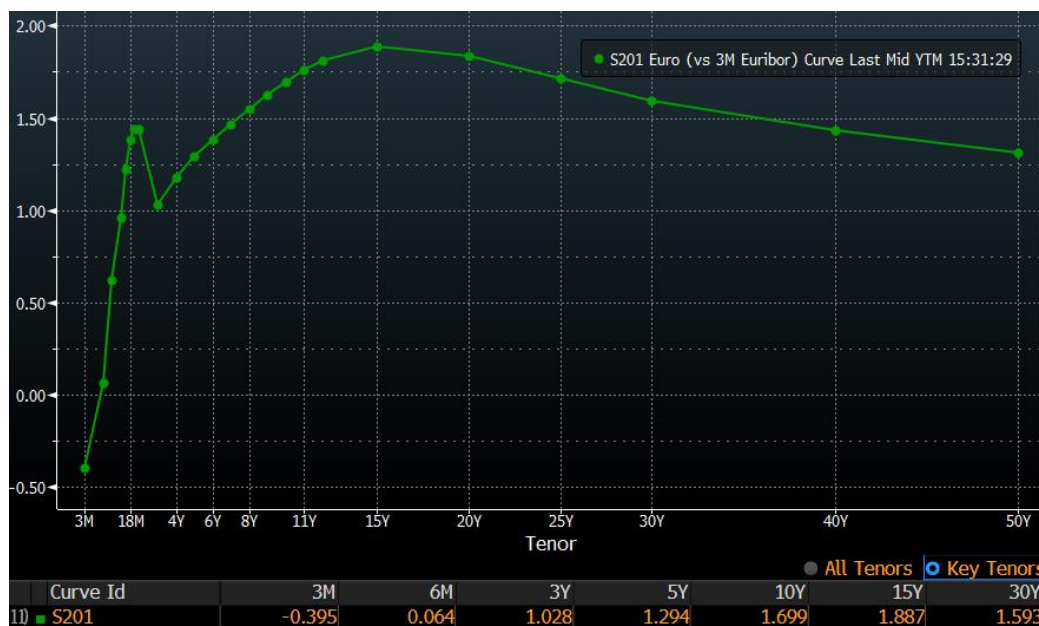


Figure 14: Euro Swap Curve (Source: Bloomberg, as of 16 May 2022)

While the EURIBOR is largely unchanged, this is different for the Euro overnight rate. Discount rates are no longer bootstrapped from EONIA OIS but from €STR OIS instead. However, this change has already taken place in October 2019. Furthermore, markets had already been acquainted with OIS discounting. The underlying market of the RFR has slightly changed, as €STR is a borrowing (deposit) rate instead of a lending rate, so it is slightly lower than EONIA. Therefore, it indirectly affects the entire swap valuation and curve building. Price alignment interest (interest on collateral) switched from EONIA to €STR (London Clearing House [LCH], 2022a).

In summary, interest rate swaps linked to EURIBOR are to a great extent the same as before the reform. The floating leg is indexed to a forward looking, credit risky interest rate. The fixing is in advance. The main difference is the switch from EONIA OIS to €STR OIS discounting. The nature of IRS referencing EURIBOR would be fundamentally transformed should EURIBOR be discontinued in the future. In this case, IRS contracts covered by ISDA would fall back on €STR compounded in arrears plus a spread with the observation period shifted backwards a few days to keep payment dates the same. The spread would be calculated and fixed by Bloomberg as detailed in their IBOR Fallback Rate Adjustments Rule Book. The following chapter on IRS referencing US Dollar interest rate benchmarks hints at what a fixed-for-RFR swap might look like.

5.3 IRS referencing US Dollar Benchmark Rates

The last day of publication of USD LIBOR will be 30 June 2023, and since the beginning of 2022 no new contracts have been allowed to reference USD LIBOR. The ARRC strongly advocates for the USD RFR, SOFR, to replace USD LIBOR as no other unsecured term lending rate is set to replace USD LIBOR. This means interest rate swaps in USD markets are shifting from fixed-for-IBOR to fixed-for-RFR.

To understand the new and current market conventions for interest rate swaps, this paper looks at interest rate swap products that are eligible for clearing at some of the world's largest central clearing counterparties (CCPs). The line chart on the left below illustrates the clearing rates of fixed-for-float swaps (red line) and OIS (yellow line), which lie above 90%. The bar chart to the right shows that most of these interest rate swaps are cleared by LCH (London Clearing House), followed by CME (Chicago Mercantile Exchange) and Eurex.

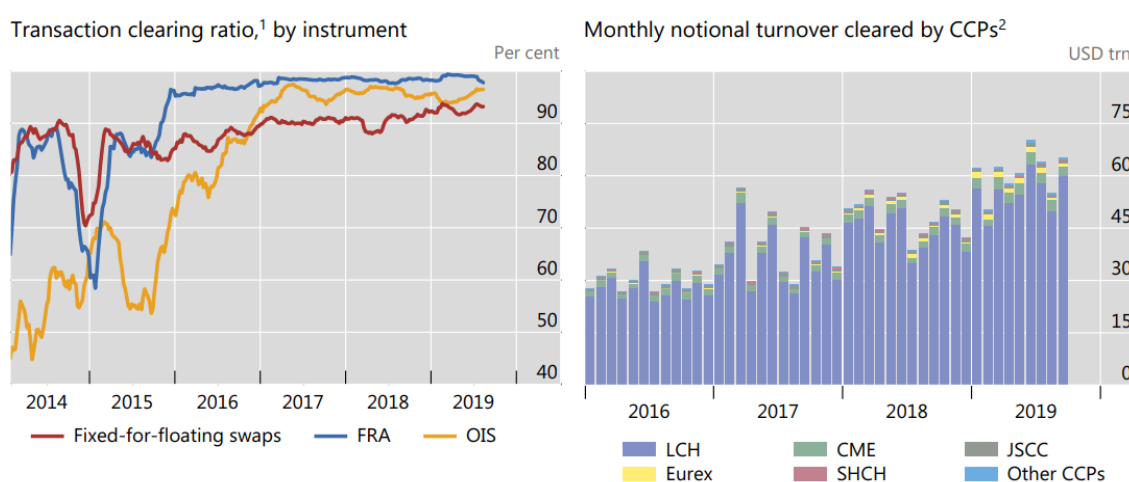


Figure 15: Clearing Ratio and CCP Clearing Volume (Ehlers and Hardy, 2019, p. 77)

With such a substantial share (>90%!) of interest rate swaps cleared virtually entirely by LCH, CME, and Eurex, it is sensible to study the swap conventions that are traded by these three CCPs.

Interest rate swaps indexed to LIBOR would convert to the ISDA's fallback on the index cessation effective date, 3 January 2022 (or after 30 June 2023 for USD LIBOR tenors excluding one week and two months). The CCPs, however, are leading their own IBOR to RFR transition before the index cessation effective date. Under the ISDA fallback convention, LIBOR is replaced by the RFR compounded in arrears and a credit spread adjustment is added to the RFR. Moreover, the observation period is shifted backwards, but the payment date remains unchanged. The backwards shift is not in line with the market standard OIS convention. Therefore, clearinghouse members urged the CCPs to convert their LIBOR interest rate swaps to RFR-linked contracts following the standard market convention for OIS before the index

cessation effective date. The figure below contrasts the interest rate swap convention following LIBOR, ISDA fallbacks, and OIS (graph based on CME 2021b, p. 2).

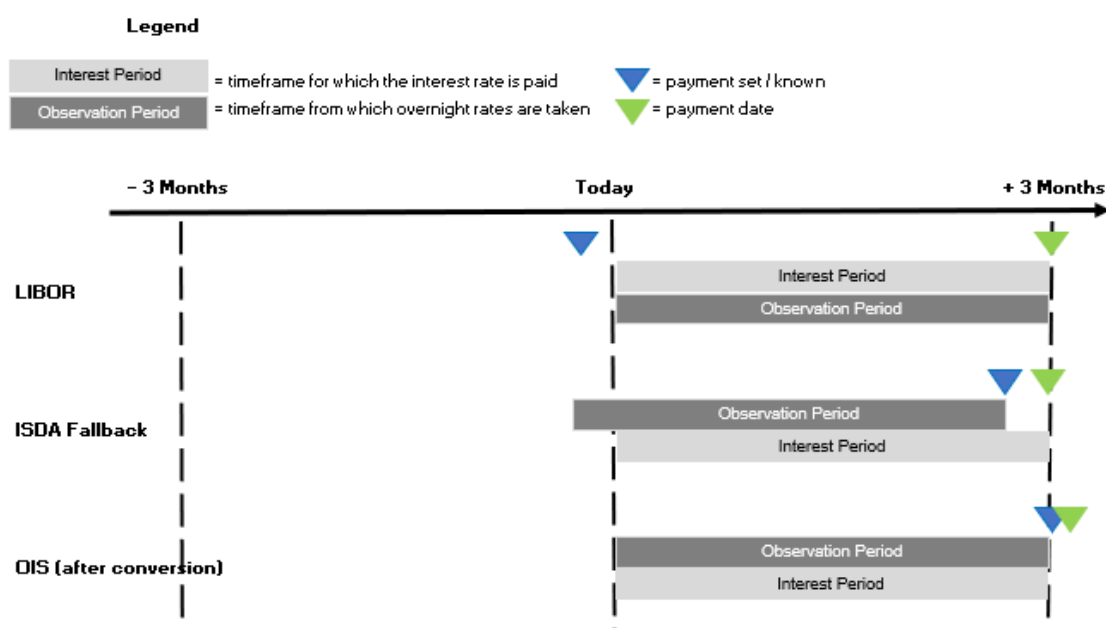


Figure 16: Comparison of IRS Fixing Conventions

The conversion methodology and dates are the same for LCH, CME, and Eurex. The LIBOR swap was terminated and replaced with the corresponding RFR OIS. The RFR is compounded in arrears and the ISDA Fallback Spread Adjustment calculated by Bloomberg is added on top (non-compounded). The observation and interest period are the same (there is no shift) and there is a payment delay. The non-LIBOR side of the swap does not change. There was a one-time cash payment to adjust for any NPV differences between the old IBOR swap and the new RFR OIS. On 3 December 2021, CHF, EUR, and JPY LIBOR and on 17 December GBP LIBOR contracts were converted. Interest rate swaps linked to USD LIBOR will be converted shortly before 30 June 2023. Conversion dates are the same across LCH, CME, and Eurex. After the conversion date, interest rate swaps referencing these LIBORs are no longer eligible for clearing (information aggregated from all CME, Eurex, and LCH sourced cited in the bibliography)

In summary, central clearing counterparties converted legacy LIBOR swaps to the corresponding RFR swaps plus spread with market standard OIS conventions. Because these legacy swaps now follow the standard RFR OIS terms, they will be better tradeable with new contracts after the transition. The fungibility of swaps following the ISDA fallback convention was unclear before the transition. Furthermore, market infrastructure and back-office systems are already set up to process standard OIS. By keeping the spread adjustment, discounting risk

and duration is kept similar (CME, 2021, p. 2). If the spread was not added cashflows would be different than before the conversion, which reduces hedge effectiveness and changes risk sensitivity (LCH, 2021b).

Besides studying what happens to legacy contracts, the CCPs publish product eligibility conventions.⁷ Only products following these conventions are eligible for clearing. SOFR interest rates swaps are referred to as “SOFR OIS” and the conventions are the same as for EFR OIS. SOFR is compounded daily to which a spread (non-compounded) may be added. The floating rate (SOFR) is fixed in arrears, so at the end of the interest period, and there is a payment lag of two days. The simplified and fictitious IRS term sheets below compare the swap conventions for USD LIBOR swaps and the market standard SOFR OIS (based on CME 2021a, pp. 13-27).

⁷ Product eligibility specifications can be found in appendix E

Features	Fixed vs. 3M USD LIBOR	Fixed vs. SOFR
Notional	10,000,000	10,000,000
Trade Date	12.04.2022	12.04.2022
Maturity Date	12.04.2027	12.04.2027
Fixed Rate	1.00%	1.00%
Fixed Leg Payment Freq	3M	3M
Float Leg Index	3M-USD-LIBOR	USD-SOFR-COMPOUND
Fixing	In advance	In arrears
Float Leg Index Tenor	3M	1D
Float Leg Payment Freq	3M	3M
Float Leg Payment Lag	n/a	2D
Float Leg Spread	-	26.161 bps, non-compounded
Float DayCountConvention	ACT/360	ACT/360

Figure 17: Fictitious SOFR OIS Termsheet

Most USD interest rate swaps should adopt the market standard outlined above. First, regulators mandated that no new contracts be created after 2021 that reference USD LIBOR. Second, market participants will have to trade IRS along CCP-set standards, as to be eligible for clearing. Third, USD LIBOR legacy contracts should be converted to market standard SOFR OIS shortly before 30 June 2023. It is reasonable to assume this is or will be the emerging market convention for SOFR-linked interest rate swaps. Otherwise, market participants could not adhere to clearing requirements mandated by regulators. Furthermore, clearinghouse members, so market participants themselves, were involved in the conversion process for legacy LIBOR swaps and voiced their preference for market standard OIS contracts. CCPs actions will ultimately be driven by the demands of their members. Additionally, one market standard enhances the liquidity of the swaps and reduces basis risks. This swap convention for SOFR is already known from Fed Funds OIS.



Figure 18: SOFR Swap Curve (Source: Bloomberg as of 16 May 2022)

For interest rate swaps referencing US Dollar the floating leg is no longer indexed to USD LIBOR, but to SOFR instead. This means the methodology, underlying market, and economic meaning behind the rate on the floating leg has fundamentally changed. First, SOFR is not a forward-looking term rate, so the fixing of the interest rate happens at the end of the interest period (fixing in arrears) with a two-day payment lag. Operationally, the in arrears fixing gives parties to IRS less time to plan their cash inflows and outflows from or to the floating leg. Second, SOFR is an overnight rate and is collateralized (secured), unlike USD LIBOR. This means it does not contain a term premium and is nearly risk free. As a result, the fair fixed rate one would be willing to pay in exchange for SOFR is lower than for USD LIBOR.⁸ Lastly, OIS discounting and price alignment interest shifted from the Federal Funds Rate to SOFR.

SOFR OIS is synonymous for an interest rate swap with the floating leg indexed to SOFR. For a SOFR OIS, the fixed rate would be taken from the SOFR swap curve. The swap curve is the result of market participants trading SOFR swaps. Bids indicate the fixed rate received in exchange for paying compounded SOFR. The asks reflect the fixed rate to be paid for receiving compounded SOFR. Compounded SOFR would be calculated using the formula from appendix B and as illustrated in the table below with fictitious numbers.

⁸ SOFR swap curve versus 3M USD LIBOR swap curve can be found in appendix F

Day	Date	Accrual Days	SOFR in %	Calculating the effective rate	Effective rate in %	Interest	Notional + Accrued Interest
Friday	01.04.2022	3	1.72	$1.72 * (3/360)$	0.01433	143.33	1,000,000.00
Monday	04.04.2022	1	1.71	$1.71 * (1/360)$	0.00475	47.51	1,000,143.33
Tuesday	05.04.2022	1	1.68	$1.68 * (1/360)$	0.00467	46.68	1,000,190.84
Wednesday	06.04.2022	1	1.67	$1.67 * (1/360)$	0.00464	46.40	1,000,237.52
Thursday	07.04.2022	1	1.69	$1.69 * (1/360)$	0.00469	46.96	1,000,283.92
Friday	08.04.2022	3	1.71	$1.71 * (3/360)$	0.01425	142.55	1,000,330.87
Monday	11.04.2022	1	1.68	$1.68 * (1/360)$	0.00467	46.69	1,000,473.42
							1,000,520.11

Figure 19: Exemplary Calculation of Compounded SOFR

The first SOFR quote of 1.72% comes from a Friday, which means it will also be applied on Saturday and Sunday, hence interest accrues at this rate for three days. Since SOFR quotes are annualized, the effective interest rate is calculated as $1.72\% * (3/360) = 0.01433\%$. The floating leg uses compounded SOFR, so the next SOFR rate from Monday is applied to the original notional plus accrued interest $1.71\% * (1/360) * 1,000,143.33$. This calculation continues until the accrual end date, at which point the floating rate for the interest period can be determined (User's Guide to SOFR p.30, 2021). Discount rates are bootstrapped from the SOFR swap curve.

The fact that the US market no longer has a credit sensitive rate will complicate banks' asset-liability management. Bank lending products referencing SOFR will need a higher spread component, since the SOFR is lower than USD LIBOR. This means finding the correct spread will be crucial, as a larger chunk of the interest received will come from the credit spread. Additionally, cash products might have different fixing conventions. Both factors heighten basis risk when hedging these products with SOFR interest rate swaps. An indication of the market's desire for a credit-risky rate comes from the ARRC's credit sensitivity group outlined earlier and from the fact that CCPs have started offering clearing for BSBY swaps in response to customer demands (LCH, 2022c). BSBY is the Bloomberg Short-Term Bank Yield Index, which is a forward-looking, credit risky interest rate benchmark (Bloomberg, 2022). The official sector (i.e. the ARRC) is not offering any guidance, so it remains to be seen if and how credit risk will be incorporated into USD interest rate swaps.

Furthermore, some USD cash products will reference the SOFR term rate. The floating leg in interest rate swaps can reference the SOFR term rate, in which case the fixing would be in advance as it was for USD LIBOR. However, IRS can only be indexed to the SOFR term rate for "end-user facing derivatives intended to hedge cash products that reference the SOFR Term Rate" (ARRC, 2021b, p. 3). While the term rate should be like the rates implied by SOFR OIS, cash products or loans indexed to it cannot be directly hedged by one SOFR OIS contract. This is because the term rate reflects market expectations while OIS will return the actual movement of SOFR. The term rate can be hedged dynamically using multiple SOFR OIS as outlined in the ARRC's 2021 Updated User's Guide to SOFR. For example, a market

participant would like to hedge (1) quarterly payments of term SOFR over one year by converting them to a fixed rate. This is done by (2) entering into a 12-month SOFR OIS paying fix and receiving quarterly compounded SOFR. Next, the market participant would (3) enter into 3-months SOFR OIS at the start of each quarter receiving fix and paying compounded SOFR. The table below illustrates the cash flows. Cash flows that cancel each other out have the same color.

Quarter	(1) Quarterly Payments of Term SOFR	(2) 12M OIS		(3) New 3M OIS at start of each quarter	
1	Pay term SOFR	Pay fix	Rec SOFR	Pay SOFR	Rec fix
2	Pay term SOFR	Pay fix	Rec SOFR	Pay SOFR	Rec fix
3	Pay term SOFR	Pay fix	Rec SOFR	Pay SOFR	Rec fix
4	Pay term SOFR	Pay fix	Rec SOFR	Pay SOFR	Rec fix

Figure 20: Hedging the SOFR Term Rate

The SOFR payments received from the 12M OIS can be used to make the SOFR payments on the 3M OIS (blue text in table). The fixed rate received on the 3M OIS will be equal to the term SOFR and can be used to make the term SOFR payments (red text in table). This only leaves the market participant to make fixed payments on the 12M OIS, successfully converting the initial floating rate exposure from the SOFR term rate into fixed payments. This example illustrates that for asset-liability management purposes, the forward looking SOFR term rate will not be fully hedged by a standard OIS contract. Dynamic hedging and multiple OIS are needed, hence complexity and transaction costs increase (ARRC, 2021a, p. 28).

As the transition is still ongoing in US Dollar interest rate markets, market standards are still evolving and could change in the future. This description is a snapshot of current conventions and expected future developments. Conventions might change going forward. The new standard interest rate swap seems to be SOFR OIS for USD interest rate markets. For Euro interest rate markets, the USD market offers a glimpse of what might happen to IRS referencing EU-RIBOR should EURIBOR be discontinued in the future and instead reference €STR.

Lastly, basis swaps referencing the new RFRs have come into existence. Basis swaps are float-for-float swaps, so two floating interest rates are exchanged. In the US market, this would generally be EFR versus SOFR and USD LIBOR versus SOFR basis swaps. For the Euro, €STR versus EURIBOR basis swaps would be the most common. Basis swaps can be used when the floating rates on the asset and liability side differ (Hull, 2018, p. 177).

5.4 Cross Currency Swaps

It is also possible to exchange interest rates in different currencies, for example, paying USD LIBOR and receiving EURIBOR in return. These swaps are called cross currency swaps, and they have slightly different features than plain-vanilla interest rate swaps. First, there are two notional amounts, as each leg is in a different currency. Second, the notional amounts in cross currency swaps are exchanged at the initiation and end of the swap contract. The notional amounts are typically determined according to the exchange rate at initiation (Hull, 2018, p. 169).

Like plain vanilla swaps, cross currency swaps can be used to transform assets and liabilities, in this case from one currency into another. This is usually done to hedge foreign currency exposure and for maturities longer than one year. Another use case of cross currency swaps is the realization of comparative advantages. A domestic borrower will find it easier and cheaper to borrow in the domestic currency compared to a foreign borrower with the same credit quality. The borrowings can then be swapped into the desired currency at better conditions (Hull, 2018, p. 170-172).

For the valuation of a USD LIBOR for EURIBOR cross currency swap before the reform, the forward rates would be discounted using the risk-free rates of each respective currency and converted using the current exchange rate to make the cash flows comparable. Like vanilla IRS, the value at initiation is zero (Hull, 2018, pp. 172-173). As the two interest rates are not entirely equivalent, however, a spread has to be added to one leg to make the transaction fair. Whether the spread is positive or negative and to which leg it is added depends on market conventions. For EURUSD cross currency swaps, the spread is added to the Euro leg (Heidorn and Mamadalizoda, 2019, p. 8).

The spread on the Euro leg is the cross-currency basis and has historically been negative. According to covered interest parity (CIP), FX forward prices are the result of interest rate differentials between two currencies. This means a EURUSD cross currency swap should theoretically trade without any basis i.e. with a spread of zero. However, this is not the case, implying there is some hidden cost or benefit to holding or transacting in one currency over the other. Heidorn and Mamadalizoda (2019) explain the basis in terms of credit risk, funding liquidity, measurement error, demand imbalances, and arbitrage constraints. As the credit risk between the USD and EUR interbank rates diverges, the basis increases. The basis is also affected by demand and supply of a particular currency. During the financial crisis and the European sovereign debt crisis, for example, cash lending was reduced, leading to a US Dollar shortage that was satisfied through the cross-currency swap markets, increasing the basis (Brophy et al., 2019, p. 8). The diverging monetary environment between USD and EUR interest rate markets likewise affects the basis. Due to the ECB's ultra-loose monetary policy, Euro interest rates were lower than US Dollar rates. European companies would thus go to USD markets in search of yield. US companies would borrow low in Euros and exchange their borrowings into USD (Heidorn and Mamadalizoda, 2019, pp. 19-20). The higher demand for USD increases the cross-currency basis (basis becomes more negative). Thus, there is a premium to be paid to acquire US Dollars (Brophy et al., 2019).

As the publication of USD LIBOR will cease after 30 June 2023 and new RFRs have come into existence, how are EURUSD cross currency swap conventions evolving? Under the SOFR First initiative, interdealer brokers were encouraged to change the LIBOR leg of cross currency swaps to the respective RFR as of 21 September 2021 for CHF, GBP, JPY, and USD. The initiative was extended to cross currency swaps referencing other currencies (including EUR) starting 13 December 2021 (CFTC, 2021a; 2021b). In response, the EUR risk-free rates working group recommended the adoption of €STR for the EUR leg of EURUSD cross currency swaps (ESMA, 2021). Even before, the cross-currency markets were moving from IBOR-for-IBOR to RFR-for-RFR, as shown in the following graphic. Since October 2021, approximately 80% of EUR/USD cross-currency swaps as measured by notional traded €STR vs. SOFR instead of EURIBOR vs. USD LIBOR (Barnes, 2021)

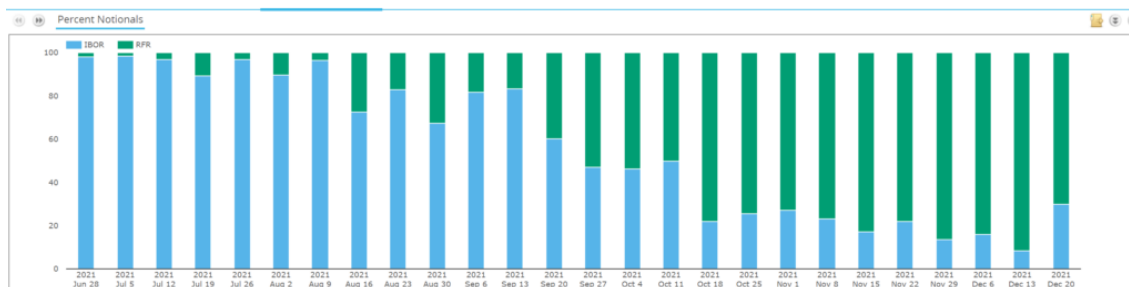


Figure 21: Adoption of RFRs for EURUSD Cross Currency Swaps (Barnes, 2021)

In August 2018, the ARRC's market structures working group first met with other national working groups to discuss interdealer cross currency swap market conventions, specifically for cross currency swaps referencing RFRs. The working group's recommendations were discussed with buy side, sell side, and intermediary market participants, and finalized in January of 2020. The working group has tried to align their guidance with OIS market conventions. Principal amounts are exchanged at the start and on the swap's maturity. A quarterly reset of the notional is recommended, meaning the notional is adjusted and cash-settled to reflect movements in the exchange rate and reduce counterparty risk. The payment frequency of each leg is quarterly. The interest rate to be paid is calculated by compounding the daily RFR rates. This means the final rate is only known at the end of the interest period, so the fixing is in arrears. The payment offset is potentially tricky, as it is two days for SOFR OIS and only one day for €STR OIS. This means either interest payment dates or rate fixing dates will not align. Here, the working group advocates adjusting payment lags, especially to achieve alignment of principal payment dates (ARRC, 2020, pp. 3-5).

The basis on the €STR/SOFR cross currency swaps is still negative and added to the Euro leg. This makes sense, as the fundamental reason behind the basis (high demand for USD) has not changed. Exchanging the RFRs is sensible, in that two risk-free overnight rates are more comparable than exchanging EURIBOR for SOFR, which is also a possibility. However, if the RFR is liquid, it is more likely that market participants would enter the RFR-RFR cross currency swap and then an RFR-IBOR basis swap (ARRC, 2020, p. 6). The basis on the €STR/SOFR cross currency swaps is higher than for the EURIBOR/USD LIBOR swap. One

possible explanation is that EURIBOR and USD LIBOR were more comparable, because they both captured unsecured interbank borrowing rates. The RFRs, however, differ with respect to their credit risk, as SOFR is a secured rate, collateralized by US Treasuries, whereas €STR is an unsecured rate. Furthermore, the “old” IBORs and “new” RFRs are measured differently. Rates no longer reflect expert opinion but are based on actual transactions. Also, the market segment has shifted from interbank to wholesale. Both could affect the interest differential between the two currencies. The following graph shows the basis for five-year €STR/SOFR (blue line) and EURIBOR/USD LIBOR cross currency swaps (white line), with quarterly payment frequencies. After 31 December 2021, when no new USD LIBOR business was to be done, the data for EURIBOR/USD LIBOR cross currency swaps ceases.



Figure 22: EURUSD Cross Currency Basis (Source: Bloomberg, as of 7 May 2022)

The fallbacks for cross currency swaps are agreed on a case-by-case basis. Under ISDA’s fallback protocol, unaffected IBOR legs will remain as they are. The affected IBOR leg’s fallback is the same as for plain-vanilla IRS: the RFR is compounded in arrears plus adjustment spread, and the payment dates remain as before (ISDA, 2021, pp. 2-3). However, the ARRC’s market structures working group has noted that the option of moving both IBOR legs to the corresponding RFR might be valuable, instead of leaving one to reference an IBOR.

6. Conclusion

The objective of this paper was to explore how the IBOR Reform affects interest rate swaps. First the IBOR Reforms were summarized, focusing exclusively on the Euro and US Dollar. Next, the features of the new (nearly) risk-free overnight rates (RFRs) were outlined and contrasted with the IBORs. Building on this, the impact of the reforms on interest rate swaps could be analyzed.

The focus was placed on benchmark reforms for the Euro and US Dollar, as they are the two most important currency jurisdictions for financial markets. Their most prominent IBORs, EURIBOR and USD LIBOR respectively, now measure wholesale instead of interbank borrowing costs. Furthermore, their calculation methodology has been adjusted to include and prioritize transaction-based data over expert opinion. For the (hybrid) EURIBOR, however, most quotes are still based on expert opinion, posing the risk of future discontinuation. Publication of USD LIBOR will cease completely after 30 June 2023, and there is no unsecured forward-looking interest rate to replace it. Since the start of 2022, regulators have barred new USD LIBOR business. It is being replaced by the USD RFR – the Secured Overnight Financing Rate (SOFR). For the Euro, €STR is the successor overnight RFR to EONIA.

In contrast to IBORs, which are term rates, RFRs are overnight rates. As such, their behavior and features differ from those of IBORs. Understanding these differences is crucial to assess the resulting effects on interest rate swaps. First, overnight rates depend on short-term liquidity needs in the market, which makes them more volatile than IBORs on a day-to-day basis. However, it is hugely impractical to pay the overnight rate daily, so instead the sequence of overnight rates is compounded over the interest period and paid only once at the end of each interest period. This has multiple important implications. First, the RFRs are not forward-looking, meaning interest payments are fixed at the end of the interest period (in arrears) instead of at the start like IBORs. Second, RFRs reflect the actual return over the interest period using a sequence of overnight investments. Interest rates are not shifted into unnatural periods, like LIBOR in arrears products, so no convexity adjustment is needed. The compounded average (i.e. sequence of overnight rates) is less volatile than IBORs. Third, the RFRs do not contain credit risk but are (nearly) risk free, complicating banks' asset-liability management.

The effects on Euro IRS are minor. The Euro has retained its credit-risky and forward-looking benchmark rate in the EURIBOR, although the inputs and the calculation methodology behind it have slightly changed. The floating leg thus references the same index as before, and the rate is still set in advance. However, the implicit credit risk has shifted, as the underlying market now includes wholesale, and EURIBOR is not anymore the rate at which a bank would borrow, but it is now its funding rate. The largest adjustment has been the shift from EONIA to €STR OIS discounting. However, this change already occurred in October 2019 and markets had been acquainted with OIS discounting before. Thus, interest rate swaps linked to EURIBOR are to a great extent the same as before the reform.

Interest rate swaps linked to USD LIBOR have undergone more drastic changes. Already, new contracts may not reference USD LIBOR, which after 30 June 2023 is set to phase out completely. The replacement as advocated by the ARRC and as indicated by clearing houses is SOFR compounded in arrears. The floating leg is thus indexed to an interest rate that measures a fundamentally different underlying market. First, the rate is no longer forward-looking, so the floating rate is set at the end of the interest period (in arrears) with a two-day payment lag. Second, SOFR is a secured overnight rate, so it does not contain a term premium and is nearly risk free unlike USD LIBOR. One direct result is a lower swap rate. Moreover, banks no longer have an interest rate that captures their funding costs. Basis risk, complexity, and transaction costs will likely increase as banks have to figure out how to hedge cash and lending products with different SOFR conventions. In conclusion, the new market standard USD interest rate swap is a SOFR overnight indexed swap.

Looking to the future, interest rate swaps referencing EURIBOR are not expected to undergo further changes, as reforms for the Euro benchmark rates have largely concluded. The most prominent matter outstanding is a forward-looking rate based on €STR, which is currently in construction. The ARRC has already developed one based on SOFR, namely CME Term SOFR. IRS are allowed to reference term SOFR in some instances, in which case the floating rate would be set in advance. A potential future discontinuation of EURIBOR would fundamentally transform Euro interest rate swaps. In this case, IRS contracts covered by ISDA would fall back on €STR compounded in arrears plus a non-compounded credit adjustment spread. The observation period is shifted backwards as to keep the payment dates the same. The fallback is the same for USD LIBOR, of course falling back on SOFR instead of €STR. It remains to be seen if and how credit risk might be incorporated for USD interest rate swaps in the future. The ARRC's credit sensitivity group and CCPs clearing of IRS indexed to the Bloomberg Short-Term Bank Yield Index both point to market participants' desire for a credit-risky rate.

Lastly, the paper briefly analyzed the IBOR Reform's impact on EURUSD cross currency swaps. The emerging market standard is exchanging €STR for SOFR instead of EURIBOR for SOFR. The basis on €STR/SOFR is larger than for EURIBOR/USD LIBOR cross currency swaps. EURIBOR and USD LIBOR were more comparable because they both captured unsecured interbank borrowing rates. The RFRs, however, differ with respect to their credit risk, as SOFR is a secured rate, whereas €STR is an unsecured rate. Cross currency swap conventions largely remain as before, for example notional amounts are still exchanged at swap initiation and maturity. The major adjustment, as for any IRS floating leg switching from IBOR to RFR, is that it pays the RFR compounded in arrears. One issue is the payment lag, which is one day for €STR and two days for SOFR. Contracts should be adjusted to align the dates on which interest payments and notional amounts are exchanged.

The research was limited in that it mostly draws from public sources like central banks, financial regulators, risk-free rates working groups, benchmark rate administrators and so on. On the one hand, these sources are directly responsible for the reforms and steer them, making them indispensable. On the other hand, insights from "end users" of the interest rates, especially banks, could provide an additional perspective. Therefore, the research could be enhanced if more information was sourced from market participants. Market participants' views were indirectly accounted for through their contributions to working groups (like the ARRC) and through actions taken by clearing houses like LCH, which respond to their members' demands. A further limitation is the recency of the reforms, which have not even fully concluded. EURIBOR may yet cease to exist and a €STR term rate is still in development. At the time of writing, USD LIBOR will be around for another year, and it is unclear if and how credit risk might alternatively be incorporated by market participants. Related to this issue and another limitation is the dearth of academic sources on the IBOR Reform and its impacts on interest rate swaps. Thus, the research could be enhanced by coming back to this topic in a few years' time. By then, market conventions should have settled, liquidity moved to certain rates, and more academic research will have been done. Positively, this paper can offer a contemporary view of the reforms and can be built on by further research.

Further research could analyze the effects of the IBOR Reforms on other interest rate derivatives, like futures, caps and floors, options, and swaptions. Further research could also look

deeper into the IBOR Reform's impact on banks' treasury departments and their asset-liability management.

Once the IBOR reforms have concluded and the transition is fully completed, its effects will become clearer. Did the reforms initiated by regulators and central banks make financial markets more complex, costly, and introduce additional risks? Or were the reforms prescient and moved markets towards a safer and better equilibrium?

7. Appendices

Appendix A

Global OTC Derivatives Market as of H1 2021

H1 2021	Notional amounts outstanding	% of total	Gross market value	% of total
Interest rate contracts	488,099	80.0%	8,940	70.9%
FRAs	73,626	12.1%	210	1.7%
Swaps	372,376	61.0%	8,058	63.9%
Options	41,810	6.9%	671	5.3%
Foreign exchange contracts	102,471	16.8%	2,412	19.1%
Equity-linked contracts	7,506	1.2%	730	5.8%
Total	609,996	100.0%	12,617	100.0%

Source: Created using data from BIS Semiannual OTC Derivatives Statistics Explorer as of 1 March 2022 (BIS, 2022)

Appendix B

Formulas behind the calculation of the SOFR averages, the SOFR index, and how to calculate SOFR averages for custom time periods from the SOFR index

$$SOFR\ Average = \left[\prod_{i=1}^{d_b} \left(1 + \frac{SOFR_i \times n_i}{360} \right) - 1 \right] \times \frac{360}{d_c}$$

Where:

- $SOFR_i$ = SOFR applicable on business day i
- n_i = number of calendar days for which $SOFR_i$ applies (often 1 day, or 3 days for typical weekend)
- d_c = the number of calendar days in the calculation period (that is, 30-, 90-, or 180- calendar days)
- d_b = the number of business days in the calculation period
- i denotes a series of ordinal numbers representing each business day in the calculation period

$$SOFR\ Index = \begin{cases} 1.00000000, & i = April\ 2,\ 2018 \\ \prod_{April\ 2,\ 2018}^i \left(1 + \frac{SOFR_i \times n_i}{360} \right), & i > April\ 2,\ 2018 \end{cases}$$

Where:

- $SOFR_i$ = SOFR applicable on business day i
- n_i = number of calendar days for which $SOFR_i$ applies
- i represents a series of ordinal numbers representing each business day in the calculation period

Source: FRBNY, 2020b

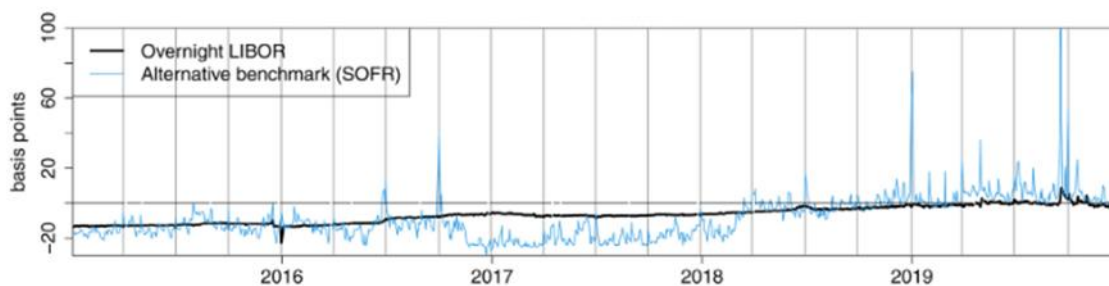
$$SOFR\ Average\ between\ x\ and\ y = \left(\frac{SOFR\ Index_y}{SOFR\ Index_x} - 1 \right) \times \left(\frac{360}{d_c} \right)$$

Where:

- x = start date of calculation period
- y = end date of calculation period
- d_c = the number of calendar dates in the calculation period

Appendix D

ON LIBOR versus SOFR showcasing SOFR spikes and quarter-end volatility



Source: Klingler and Syrstad, 2021, p. 787

Appendix E

LCH Product eligibility USD (OIS vs. RFR)

Product / Characteristic	"OIS" (FedFunds)	SOFR swaps
Types	Outright OIS	Outright OIS
ISDA Definition	USD-Federal Funds-H.15-OIS-COMPOUND	USD-SOFR-COMPOUND
Benchmark Tenor	1D	1D
Publication Date	T+1	T+1
Fixing	T+1	T+1
Payment lag	2 days	2 days
Minimum Term	7 days (original) / 2 days (residual)	7 days (original) / 2 days (residual)
Maximum tenor	51 years	51 years
Fixed Rate Payments	1M, 3M, 6M, 12M	1M, 3M, 6M, 12M
Floating Rate Payments	1M, 3M, 6M, 12M	1M, 3M, 6M, 12M
Notional/Fixed Rate/Spread	Constant - variability not supported	Constant - variability not supported
Floating Rate Spread	Eligible - Spread exclusive compounding	Eligible - Spread exclusive compounding
IMM roll dates	Eligible	Eligible
Front or Back stub	Eligible	Eligible
Front & Back stubs	Not supported	Not supported
Floating Rate Day Count Fraction	ACT/360	
Fixed Rate Day Count Fractions	30/360, 30E/360, ACT/365.Fixed, ACT/360	

Source: LCH, 2019b

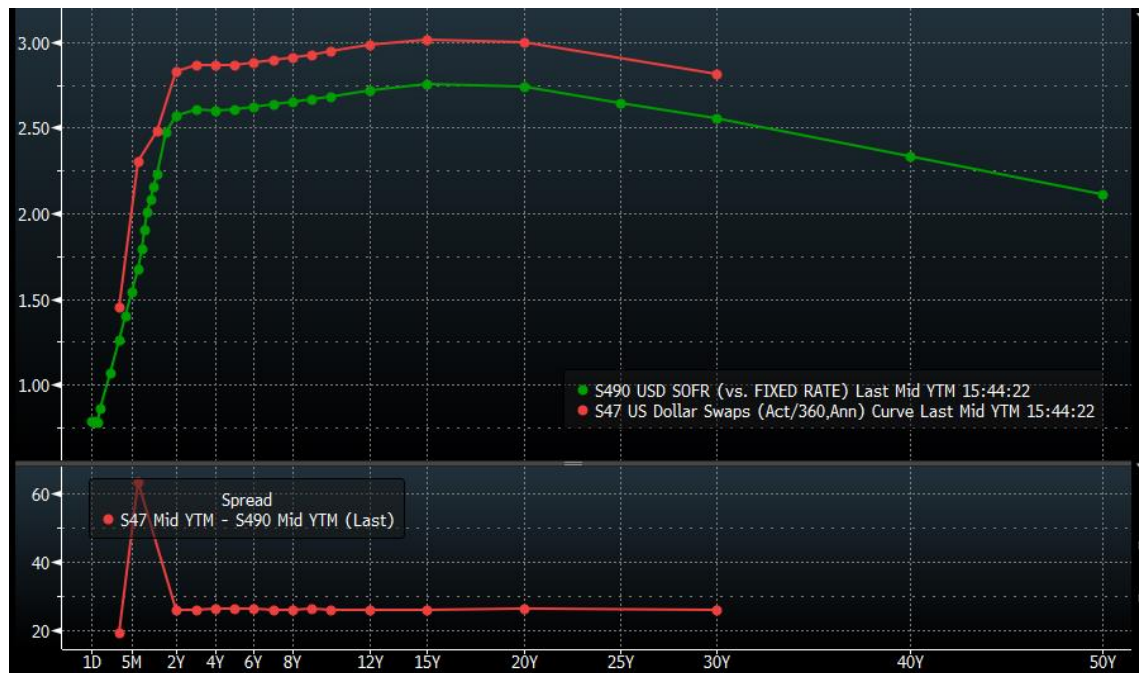
LCH Product eligibility EUR (OIS vs. RFR)

Product / Characteristic	"OIS" (EONIA)	€STR swaps
Types	Outright OIS	Outright OIS
ISDA Definition	EUR-EONIA-OIS-COMPOUND	EUR-EuroSTR-COMPOUND
Benchmark Tenor	1D	1D
Publication Date	T+1	T+1
Fixing	T+1	T+1
Payment lag	1 day	1 day
Minimum Term	7 days (original) / 2 days (residual)	7 days (original) / 2 days (residual)
Maximum tenor	51 years	51 years
Fixed Rate Payments	1M, 3M, 6M, 12M	1M, 3M, 6M, 12M
Floating Rate Payments	1M, 3M, 6M, 12M	1M, 3M, 6M, 12M
Notional/Fixed Rate/Spread	Constant - variability not supported	Constant - variability not supported
Floating Rate Spread	Eligible - Spread exclusive compounding	Eligible - Spread exclusive compounding
IMM roll dates	Eligible	Eligible
Front or Back stub	Eligible	Eligible
Front & Back stubs	Not supported	Not supported
Floating Rate Day Count Fraction	ACT/360	
Fixed Rate Day Count Fractions	30/360, 30E/360, ACT/365.Fixed, ACT/360	

Source: LCH, 2019a

Appendix F

SOFR swap curve (green line) versus 3M USD LIBOR swap curve (red line) and spread in basis points between the two curves (bottom)



Source: Bloomberg, retrieved 16 May 2022 from Bloomberg Terminal

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