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1. Abstract

The reform of the Interbank Offered Rates (IBORs) is the major transformation of the financial landscape all over the world. This reform is driven by the need to establish alternative reference rates characterized by features such as reliability, robustness, frequency, availability, and representativeness. This thesis delves into the details of the IBOR reform, exploring its historical context, motivations, and the scope of its impact.

In the Introduction chapter 3, a foundational understanding of the roots of IBOR reform will be provided, including its significance and key driving factors. In the next chapter (chapter 4) we will explore the role and the construction of reference rates, examining where they can find their application. We are going to delve into the weaknesses of the IBOR rates and define the desired features of the alternative reference rates. Furthermore, a comprehensive overview of the reform milestones will be provided. Then, in chapter 5 we will conduct an analysis of the key distinctions between IBORs and alternative reference rates within the euro and US dollar areas. Our research will encompass a comparison of their governance frameworks, estimation techniques, and an exploration of fallback provisions designed for scenarios when the reference rate becomes unavailable.

The practical part of this thesis is devoted to an investigation of impact stemming from the IBOR reform. To accomplish this, we will simulate a portfolio involving a diverse range of interest rate swaps. These swaps will be evaluated by applying distinct OIS curves. We aim to not only estimate the localized effects but also to extrapolate and estimate the broader influence of this reform on the swap market within the euro area.

2. Kurzfassung

Die Reform der Interbank Offered Rates (IBORs) stellt die entscheidende Transformation der weltweiten Finanzlandschaft dar. Diese Reform wird durch die Notwendigkeit angetrieben, alternative Referenzzinssätze zu etablieren, die durch Merkmale wie Zuverlässigkeit, Robustheit, Häufigkeit, Verfügbarkeit und Repräsentativität gekennzeichnet sind. Diese Arbeit vertieft sich in die Details der IBOR-Reform und untersucht ihren historischen Kontext, ihre Motivationen und den Umfang ihrer Auswirkungen.

Im Einleitungskapitel wird ein grundlegendes Verständnis für die Ursprünge der IBOR-Reform vermittelt, einschließlich ihrer Bedeutung und der wichtigsten treibenden Faktoren. Im nächsten Kapitel werden die Rolle und die Konstruktion von Referenzzinssätzen erkundet und untersucht, wo sie Anwendung finden können. Wir werden auf die Schwächen der IBOR-Zinssätze eingehen und die gewünschten Merkmale der alternativen Referenzzinssätze definieren. Darüber hinaus wird eine umfassende Übersicht über die Meilensteine der Reform gegeben. Dann werden wir in Kapitel 5 eine Analyse der wesentlichen Unterschiede zwischen den IBORs und den alternativen Referenzzinssätzen im Euro- und US-Dollar-Raum durchführen. Unsere Forschung wird einen Vergleich ihrer Governance-Strukturen, Schätzmethoden und eine Untersuchung von Fallback-sätzen umfassen, die für Szenarien entwickelt wurden, in denen der Referenzzinssatz nicht verfügbar ist.

Der praktische Teil dieser Arbeit widmet sich der Untersuchung der Auswirkungen der IBOR-Reform. Hierzu werden wir ein Portfolio von Zinsswaps simulieren, wo verschiedene OIS-Kurven zur Bewertung verwendet werden. Unser Ziel ist es, nicht nur die lokalen Auswirkungen abzuschätzen, sondern auch den breiteren Einfluss dieser Reform auf den Swap-Markt im Euro-Raum zu extrapolieren und zu schätzen.

Contents

3. Introduction

The IBOR Reform is one of the most significant changes in the world of capital markets since the introduction of the euro. For the long time, interbank offered rates (IBORs), which include LIBOR, EURIBOR, TIBOR, CDOR, and other similar rates, have been used as interest rate benchmarks on the global financial markets.

3.1. Background

IBOR reference rates represent a measure of the interest rate at which large banks can borrow from one another on an unsecured basis [1]. Fixing of the IBOR reference rates is based mainly on an expert opinion of a poll of selected banks. Such kind of procedure gives an opportunity for manipulation of reference rates.
One of the most considerable examples of market manipulation regarding interest rates is the LIBOR scandal. It was a series of fraudulent actions connected to the London Interbank Offered Rate and also the resulting investigation and reaction. The scandal arose when it was discovered that banks were falsely inflating or deflating their rates so as to profit from trades, or to give the impression that they were more creditworthy than they were. [2]
In order to protect the interest rates against manipulation and to fix the existing weaknesses, in the last years the alternative risk free reference rates (ARRs) were developed for the most relevant currencies.

3.2. Motivation

IBORs are used as reference rates in a wide range of financial contracts, such as loans, derivatives, securities and bank deposits, the total notional outstanding value of

which exceeds $400 trillion[1] across all currencies. Figure 3.1 presents the distribution of the notional amount linked to the different IBOR rates by the asset class. [3] LIBOR[2] is used in wholesale and retail financial products, the total amount of which is more than $240 trillion across all currencies. EURIBOR and EONIA are also used as reference rates for >$175 trillion of wholesale and retail financial products, as well as for other non-financial sectors. [3]

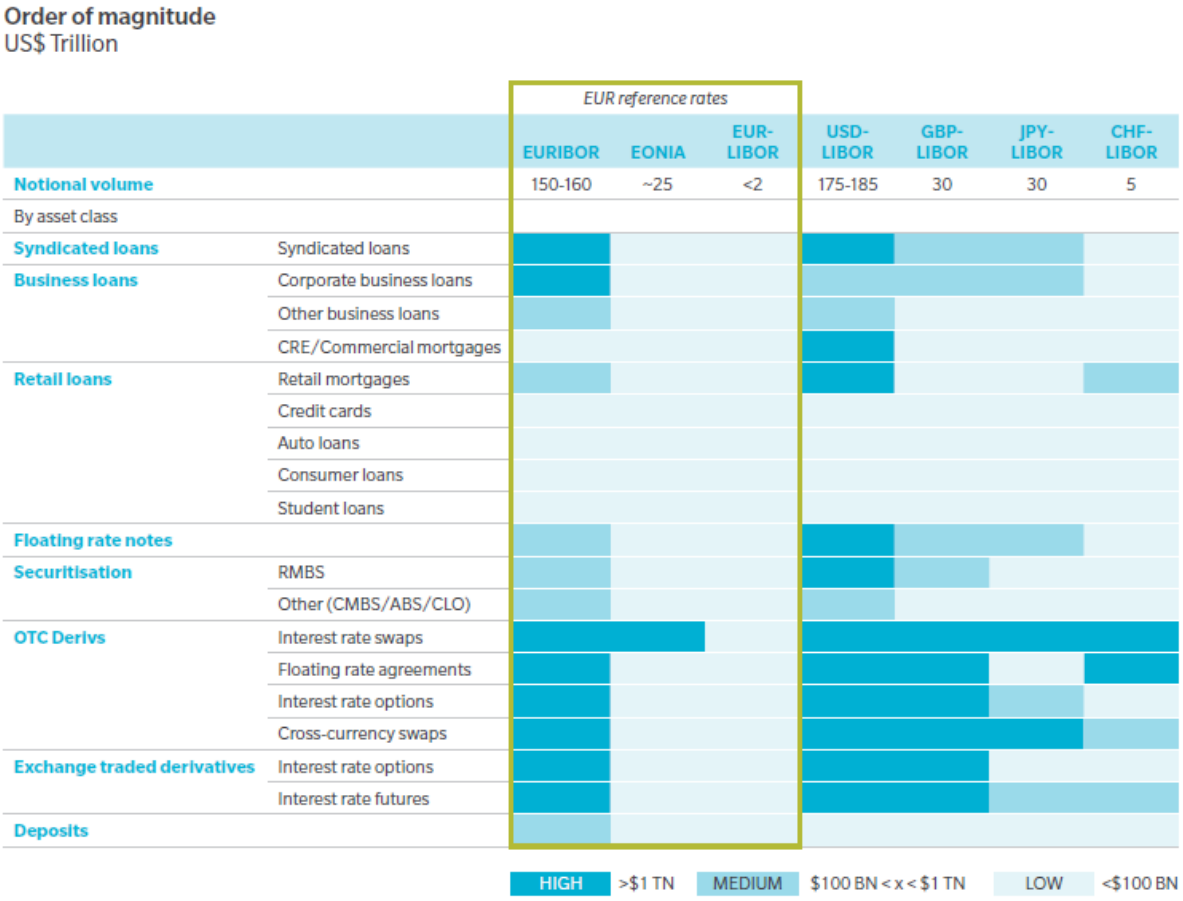

Figure 3.1.: Source: Oliver Wyman analysis, data as available as of December 2017 and updated to reflect estimates from the 2nd and 3rd meetings of the working group on euro risk-free rates [3].

The provided overview emphasizes the importance of IBOR reference rates and the IBOR reform.

[1] In this paper, trillion is employed in accordance with the American definition, which is 10^{12}.
[2] The comprehensive description of the reference rate is to be found in Table 5.3

3.3. Scope of the Study

The theoretical part of this paper will be mainly focused on the reference rates, presented in the Table 3.1. These rates represent the most important benchmarks related to the different kinds of financial products which are described in detail in subsection 4.2.

Current Rate	Replacement	Name
USD-LIBOR/Fed Funds	SOFR	Secured Overnight Financing Rate
GBP-LIBOR	SONIA	Sterling Overnight Index Average
EURIBOR/EONIA	€STR	Euro Short-Term Rate
CHF-LIBOR	SARON	Swiss Average Rate Overnight
JPY-LIBOR	TONAR	Tokyo Overnight Average Rate

Table 3.1.: Overview of identified alternative RFRs in selected currency areas.

In the practical part of this paper, the effects of the IBOR reform in the EURO-zone will be investigated.

4. Background and history of the IBOR reform

4.1. Reference Interest Rates and their role on financial markets

In the world of financial markets, reference rates are used to link payments in a financial contract to standard money market interest rates. Reference rates are being used in domestic and international financial markets, covering a wide range of unsecured and secured money markets in many currencies. As a consequence, reference rates have become an integral part of financial markets all over the world. Using reference rates reduces the complexity of financial contracts and facilitates their standardisation as the situation where each individual financial contract refers to its own customised interest rate can be avoided. This can decrease transaction costs and strengthen market liquidity. [4]

With the extension of an application scope of reference rates, the weak points of them have become more visible. Cases of market manipulation have raised concerns about the appropriateness of the processes and methodologies used in formulating reference interest rates.

In order to examine the issues related to the design and choice of reference interest rates in financial markets, the Economic Consultative Committee (ECC) agreed in September 2012 to set up a Working Group. The Group, chaired by Hiroshi Nakaso (Assistant Governor, Bank of Japan), distinguished its work from other work in this area by focusing on the role of reference interest rates from a central bank perspective. [4]

4.1.1. Construction of a reference rate

Theoretically, any market interest rate can serve as a reference rate. The following formula presents a simplified representation of the de-composition of a market interest rate:

$$IR = IR_{rf} + RP, \tag{4.1}$$

where IR_{rf} is a risk-free rate and RP is a risk premia. Risk premia can refer to a term premium, a liquidity risk premium and a credit risk premium, depending on a type and features of a particular financial instrument the rate is linked to. Term premia tend to increase with the maturity of the underlying instrument; the liquidity risk premium depends on the ease with which the money market instrument can be traded; and the credit risk premium depends on the credit quality of the borrower and, in secured funding markets, the collateral. [4]

4.2. Application scope of reference rates

This section is dedicated to the usage of reference rates in the worldwide financial market and aims to show their huge role in the functioning of the financial system. In the following, a big variety of fields where the reference rates are used is listed [5]:

1. **Credit products.** IBOR reference rates are used in a lot of different credit-based products governed by very different arrangements:
   - Loans: commercial loans, syndicated loans, floating rate bank loans, term loan market, leveraged facilities, intercompany loans, agricultural loans, student loans, credit card loans, home equity loans.
   - Structured products: asset backed securities (ABS), mortgage backed securities, commercial mortgage backed securities.
   - Short term money markets: foreign office deposits, time deposits, checking accounts, money market deposit accounts.
   - Bonds: corporate bonds, auction rate securities, agency notes, affordable housing bonds, trust preferred securities, covered bonds.

   In 2014, the start year of the IBOR Reform, Market Participants Group (MPG) on Reforming Interest Rate Benchmarks published the report with the analysis of

financial products linked to the reference rates (see [6] for more details). Table 4.1 presents the selected credit products linked to the major reference rates as of March 2014.

2. **Derivatives.** There are a lot of interest rate derivatives referenced to the IBOR rates:

   - Swaps, swaptions, options.
   - Forward rate agreements, swap futures, interest rate futures and options.

   According to the data published in the MPG Final Report currency Market Footprint, the total outstanding amount of the derivative products linked to the reference rates is much higher than those of credit products as of March 2014. The MPG has estimated that between 60% and 90% of all interest rate OTC derivatives are linked to LIBOR, EURIBOR, or TIBOR (see Table 4.2). [6] As of June 2019, the total outstanding notional amount in interest rate derivatives was around €200 TN, which accounted for two-thirds of the total euro area derivatives market according to the research of the European Central Bank (ECB) [7]. Figure 4.1 represents the interest rate derivative market in the euro area and the corresponding notional amounts as of June 2019 linked to the particular reference rate.

3. **Other products.** Besides credit products and derivatives, there is a wide range of fields were reference rates are used as well:

   - Fair value calculations for discounting provisions, impairments and financial leases.
   - Project finance and trade finance.
   - Regulatory cost of capital calculations: Discount rate for property valuations, Capital Asset Pricing Model (CAPM) to calculate regulatory cost of capital.
   - Taxes.
   - Valuation purposes: discount rates for pension liabilities and some financial instruments.

Product type	USD	% of LIBOR	EUR	% of EURIBOR
Syndicated Loans	$ 3.4TN	97%	$ 0.5TN	90%
Business Loans	$ 2.9TN	30-50%	$ 5.8TN	60%
Commercial Mortgages	$ 3.6TN	30-50%	-	60%
Retail Mortgages	$ 9.6TN	15%	$ 5.1TN	28%
Consumer Loans and others	$ 2.9TN	low	$ 1.9TN	low

Table 4.1.: Selected credit products linked to reference rates. Source: LIBOR and EURIBOR Market Footprint Overview [6].

Currency	Notional outstanding volume of OTC	Volume linked to IBOR
USD	$ 171TN	65%
EUR	$ 186TN	estimated as high
GBP	$ 46TN	62%
CHF	$ 6.1TN	98-100%
JPY	$ 24.3TN	58.3%

Table 4.2.: Selected derivatives linked to reference rates. Source: MPG Final Report currency Market Footprint overviews [6].

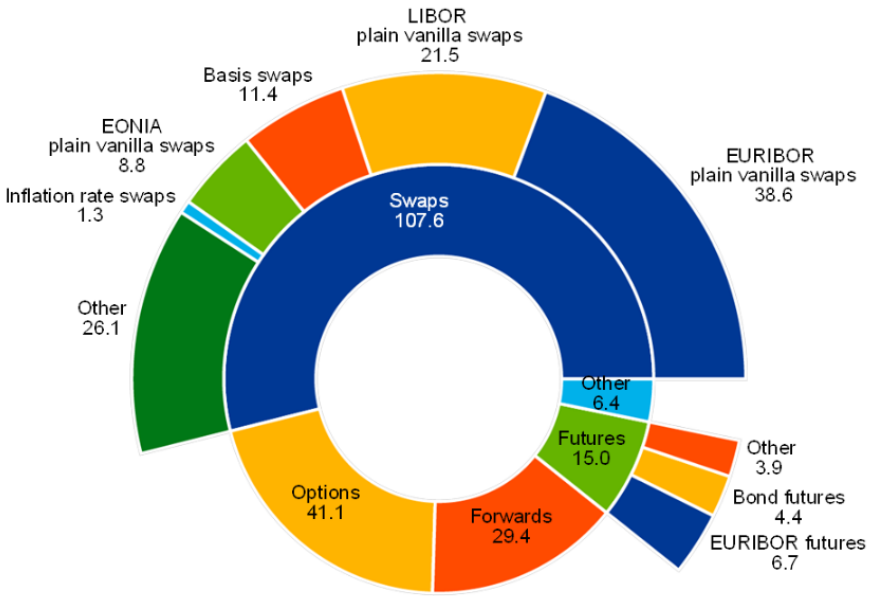

Figure 4.1.: The euro area interest rate derivatives market (in €TN). Source: EMIR data available to the ECB [7].

4.3. Desirable features of reference rates

Setting a new reference rate on the market can be challenging. On one hand, all the desirable characteristics of IBORs have to be preserved, while on the other hand, it has to be ensured that the new rates are based on actual transactions in liquid markets. The properties of the ideal reference rate have been listed in the report established by the BIS Economic Consultative Committee (ECC) [4] and further summarized in the BIS Quarterly Review [8]. Here are the 5 most important features of the ideal reference rate:

- **Reliability.** This feature can be defined as a proper governance and administration to safeguard against manipulation or error. In the context of reference rates, it is important for market integrity and functioning.
- **Robustness.** This term can be understood as an availability even under stressful market conditions. There have to be clear rules for reference rate production, including transparent and well-known fall-backs[1] in periods of market stress. Otherwise, there may be a risk of unwanted cash flow mismatches for banks, as well as other market participants, in periods when they already face difficulties.
- **Frequency.** The rates have to be calculated on a daily basis in order to ensure functioning of financial markets. It is important for the pricing and valuation of financial instruments.
- **Availability.** The rates have to be published on dedicated sites, which is important for contract verification.
- **Representativeness.** Reference rate must represent a correct basis for the pricing of financial instrument. Reference rates would have to serve as a benchmark for term lending and funding. The market participants, lenders and borrowers, require a lending benchmark that behaves not too differently from the rates at which they raise funding. For instance, banks may fund a long-term fixed rate loan to a client by drawing on short-term (variable rate) funding instruments. To hedge the associated interest rate risk, a bank may enter into an interest rate

[1] Benchmark fall-backs are replacement rates that would apply to derivatives trades referencing a particular benchmark. These would take effect if the relevant benchmark becomes unavailable while market participants continue to have exposure to that rate [9].

swap as a fixed rate payer in return for receiving a stream of floating interest rate payments determined by a benchmark that reflects the bank's funding costs. If the two types of rate diverge, the bank runs a "basis risk" between its asset and liability exposure.

4.4. Weaknesses of the IBOR rates

The major reference rates (such as LIBOR, EURIBOR, and TIBOR) were initially designed to represent the common bank credit risk premium of "prime banks". Since 2007, interest rates were not able to completely fulfil their initial role anymore. The cases of attempted market manipulation and false reporting of global reference rates, together with the post-crisis decline in liquidity in interbank unsecured funding markets, have undermined confidence in the reliability and robustness of existing interbank benchmark interest rates. Uncertainty surrounding the integrity of these reference rates represents a potentially serious source of vulnerability and systemic risk. [5]
Summarizing everything mentioned above, we can outline the main reasons why the IBORs fail to meet some of the desirable features of a reference rate:

1. The specific construction of the IBORs, i.e., expert opinion of a small set of banks, gives a lot of **space for manipulation of the reference rates**. The IBORs could be manipulated in several ways. For example, in May 2008, several global banks were alleged for reporting unjustifiably low borrowing costs for the calculation of the daily London Interbank Offer Rate (LIBOR) benchmark. [10] The complete analysis of the LIBOR manipulation case can be found in the article of Abrantes-Metz (2012) [11]. The motive to manipulate benchmarks is a desire to profit on positions in derivative financial instruments that are linked to the reference rates. Traders with large positions can benefit even in case of an insignificant change of a reference rate. In the case of IBORs, some derivative traders bank officials, that were in charge with providing rate submissions to the LIBOR poll, were able to bias their reports [1] (see Duffie and Stein (2015)).

2. IBORs are supposed to represent the rate at which major banks can borrow

from each other. Since the beginning of the GFC[2], **unsecured interbank market activity has significantly decreased** and the liquidity is mostly concentrated at shorter tenors. [4] In 2018, the Eurosystem performed a complete assessment of the euro money market and published some market trends in the Euro money market study 2018. According to this report, interbank activity within the euro area represented just 15% of total activity in the wholesale unsecured money market. [12] This tendency raised a lot of questions about the representativeness of the benchmark rates.

3. The **increased dispersion of individual bank credit risk** since 2007, however, has undermined the adequacy of the IBORs whose main goal is to capture common bank risk, even for users seeking a reference rate with exposure to credit risk [4].

In order to solve the raised issues, reform efforts have focused on linking the new benchmarks with actual transactions in the most liquid segments of money markets. It means that the new reference rates incorporate the following attributes:

- shorter tenor, essentially by moving to O/N markets, where volumes are larger than for longer-dated tenors;
- moving beyond interbank markets to add bank borrowing from a range of non-bank wholesale counterparties;
- in some jurisdictions, drawing on secured rather than unsecured transactions. The secured transactions could also include banks' repurchase agreements (repos) with non-bank wholesale counterparties.

[8].

4.5. Historical milestones of the IBOR reform

The weaknesses described in subsection 4.4 undermined the reliability of some existing benchmarks. In this context, the Financial Stability Board (FSB) has published a report questioning the reliability and robustness of some major reference rates and

[2]Global financial crisis of 2007-2008.

setting out recommendations to reform them. In 2014, the FSB was asked by the G20[3]. to undertake a fundamental review of major interest rate benchmarks and of plans for reform, to ensure that plans are consistent and coordinated, and that interest rate benchmarks are robust and appropriately used by market participants. In July, 2014 the FSB published the first report "Reforming Major Interest Rate Benchmarks" [5]. FSB defined the features relevant for reference rates :

1. The benchmark rates should minimise the opportunities for market manipulation.

2. The benchmark rates should be anchored in observable transactions wherever feasible.

3. The benchmark rates should be robust in the face of market dislocation and should command confidence that they remain resilient in times of stress.

In April-July 2017, the first suggestions for the alternative reference rates were discussed and, as of July 2017, the Chief Executive of the FCA[4] held the speech where he examined important questions about the future of LIBOR. The highlights of his speech were the following key points [14]:

- Panel banks support to sustain LIBOR until end-2021 will enable a transition that can be planned and executed smoothly.

- Work must begin in earnest on planning the transition to alternative reference rates that are based firmly on transactions.

Considering the complexities related to the implementation of the new reference rates and the materiality of changes caused by the IBOR reform, the project was split into two phases according to the two identified groups of accounting issues that could affect financial reporting:

1. **pre-replacement issues** - issues affecting financial reporting in the period before the reform;

[3]The G20 (or Group of Twenty) is an intergovernmental forum comprising 19 countries and the European Union (EU). It works to address major issues related to the global economy, such as international financial stability, climate change mitigation, and sustainable development [13].

[4]The Financial Conduct Authority (FCA) is a financial regulatory body in the United Kingdom, but operates independently of the UK Government, and is financed by charging fees to members of the financial services industry.

2. **replacement issues** - issues that might affect financial reporting when an existing interest rate benchmark is either reformed or replaced. [15]

In the following, the IBOR project milestones will be discussed.

In April 2018, FRBNY[5] and BoE[6] started with the publishing of SOFR and SONIA (new) interest rates while the methodology used to calculate the benchmark was reformed following several rounds of consultation. [16]

In September 2018, the ECB-organised private sector working group on euro risk-free rates (EUR RfR WG) recommended that the euro short-term rate (€STR) replace the euro overnight index average (EONIA) as the new euro risk-free rate. The next milestone was the 2nd October 2019 when the ECB published the short-term rate €STR for the first time. [17] Since then, the current EONIA was re-calibrated to the €STR plus a fixed spread of 8.5 basis points. This spread is an average of the EONIA - pre-€STR spread between 17 April 2018 and 16 April 2019, with a 15% trimming mechanism. The euro short-term rate (€STR) is a rate which reflects the wholesale euro unsecured overnight borrowing costs of euro area banks. [18]

Following the recommendations from the EUR RfR WG, a major milestone achieved by Eurex Clearing was the adoption of €STR for discounting EUR-denominated cleared OTC derivatives on 27 July 2020. This limits Eurex Clearing's main usage of the EONIA benchmark to the clearing of EONIA overnight index swaps and EONIA-EURIBOR basis swap. [19]

As of August 2020, The International Accounting Standards Board (IASB) has published 'Interest Rate Benchmark Reform — Phase 2 (Amendments to IFRS[7]9 Financial Instruments, IAS 39 Financial Instruments: Recognition and Measurement, IFRS 7 Financial Instruments: Disclosures, IFRS 4 Insurance Contracts and IFRS 16 Leases) with amendments that address issues that might affect financial reporting after the reform of an interest rate benchmark, including its replacement with alternative benchmark rates. The key areas addressed by the Phase 2 were

1. Practical expedient for particular changes to contractual cash flows because the

[5]Federal Reserve Bank of New York.
[6]Bank of England.
[7]International Financial Reporting Standards (IFRS) are accounting standards issued by the IFRS Foundation and the International Accounting Standards Board (IASB).

reform of an interest rate benchmark might change the basis for determining the contractual cash flows of a financial asset or liability.

2. Relief from specific hedge accounting requirements because otherwise companies would be required to discontinue hedge accounting solely due to changes required by the reform.

3. Disclosure requirements in order to capture all the useful information.

4. Transition and effective date for the application of the amendments. The amendments are effective for annual periods beginning on or after 1 January 2021, with earlier application permitted. [20]

As of October 2020, the CME Group[8] performed a discounting transition from EFFR[9] to SOFR.

In November 2020, the FSB published their progress report on the IBOR reform and ,once again, the critical importance of the reform was emphasized due to the disruption to financial markets caused by the COVID-19 pandemic which further highlighted the weaknesses of IBORs. FSB published a global transition roadmap for LIBOR. The roadmap set out a timetable of actions which had to be done in order to ensure a smooth transition of LIBOR by the end of 2021. [21]
The end of 2021 has marked a major milestone in the transition away from LIBOR [22]. In the Table A.2 the milestones of the IBOR reform are summarised in the graphical representation.

[8]CME Group is the world's leading derivatives marketplace.
[9]Effective Federal Funds Rate

5. Computation of IBOR rates

The objective of this section is to provide the comparison of IBORs and Alternative Reference Rates[1]. We will make a careful study of the computation methodology and policies for the major reference rates which are in the scope of this study (cf. Table 3.1). In the following sections we will discuss the major differences between the old and the new reference rates, as well as take a closer look at a concept of fallback rates.

5.1. Overview of the major rates

In this subsection, we present a comprehensive summary of the major Interbank Offered Rates (IBORs) and Alternative Reference Rates (ARRs) within both the euro and dollar areas. This overview serves to provide a clear and concise understanding of these critical benchmark rates and the pivotal shift towards adopting more robust and transparent alternatives.

5.1.1. EURO area

In Europe, the most widely used interest rate benchmarks for euro-denominated contracts are EONIA and EURIBOR. The main difference between them is tenor[2] - EONIA is an overnight rate, whereby EURIBOR is an interbank lending rate at various maturities. In the following, we are focusing on the overview of their main features.

[1] IBOR Reform comprises a much wider range of currencies than those in our study scope - the list of the remaining currencies with the corresponding IBORs and ARRs can be found in Appendix section A.1.

[2] Tenor refers to the length of time remaining before a financial contract expires.

Long name	Euro Interbank Offered Rate
Definition	The rate at which euro interbank term deposits are being offered within the EU and EFTA countries by one prime bank to another.
Defined tenors	1 week, 1 month, 3 months, 6 months and 12 months.
Administrator	European Money Market Institute (EMMI)
Life span	December 1998 - summer 2019.
Panel	Panel of credit institutions ("Panel Banks") that are active participants in the euro money markets.
Replacement	EURIBOR (Hybrid Methodology)
Computation	Trimmed average (15%). The calculations are done based on expert judgement.

Table 5.1.: EURIBOR Summary. Source: The European Money Markets Institute (EMMI) [23] and [24].

In case of EURIBOR, the determination has shifted from a quotes-based to a transactions-based methodology, the so-called hybrid methodology [25]. The "Underlying Interest" for EURIBOR is now stated as: "The rate at which wholesale funds in euro could be obtained by credit institutions in current and former EU and EFTA countries in the unsecured money market." The new Benchmark Determination Methodology for EURIBOR follows a hierarchical approach consisting of three levels. The first level consists of contributions based solely on transactions[3] in the underlying interest at the defined tenor from the prior TARGET[4] day. The contribution rate is the volume-weighted average rate (VWAR) of the set of eligible transactions for the defined tenor. It is estimated as

$$Contribution\ Rate = \frac{\sum_i r_i \cdot Vol_i}{\sum_i Vol_i}, \tag{5.1}$$

where r_i and Vol_i are the borrowing rate and size of the eligible transaction i, respectively. Level 2 consists of contributions based on transactions in the underlying interest across the money market maturity spectrum and from recent TARGET days,

[3]See [23] for the detailed description of eligible transactions.
[4]TARGET is the Trans-European Automated Real-time Gross settlement Express Transfer System.

using calculation techniques provided by EMMI. Level 3 consists of contributions based on transactions and/or other data from a range of markets related to the unsecured euro money market, using a combination of modelling techniques and/or the Panel Bank's judgment (for more information on Level 2 and 3 contributions please see [23]).
As a next step, for each EURIBOR tenor, the highest and lowest 15% of the final contribution rates of all Panel Banks are eliminated. The remaining rates are arithmetically averaged and rounded to three decimal places following the symmetric arithmetic rounding convention: "half away from zero" [23]. The residual EURIBOR features outlined in the Table 5.1 remain the same, i.e., EURIBOR estimated using the hybrid methodology has same tenors (1W, 1M, 3M, 6M and 12M) and EMMI remains the administrator of the new rate.

Long name	Euro OverNight Index Average
Definition	Eonia is the interbank overnight lending reference rate for the euro. The benchmark's underlying interest is the rate at which banks of sound financial standing in the EU and EFTA countries lend funds in the interbank money market in euro.
Defined tenors	Overnight (O/N)
Administrator	European Money Market Institute (EMMI)
Life span	January 1999 - September 2019.
Panel	Panel of credit institutions ("Panel Banks") that are active participants in the euro money markets.
Replacement	ESTR
Computation	Volume-weighted average

Table 5.2.: EONIA rate Summary. Source: The European Money Markets Institute (EMMI) [26] and [24].

In case of the Overnight rate EONIA, even more changes were done. In October 2019 the ECB launched the new euro benchmark €STR. The euro short-term rate is a rate which reflects the wholesale euro unsecured overnight borrowing costs of euro area banks. The rate is administrated by the ECB and is published for each TARGET2 business day based on transactions conducted and settled on the previous

day (reporting date T) with a maturity date of T+1. The rate is based on borrowing transactions in euro conducted with financial counterparties and is calculated using overnight unsecured fixed rate deposit transactions over € 1 million. It is calculated for each TARGET2 day as volume-weighed trimmed mean (25%) rounded to the third decimal. The euro short-term rate is based exclusively on the eligible data from the unsecured market segment of the MMSR[5] [18]. The €STR determination process is summarised in the Figure 5.1.

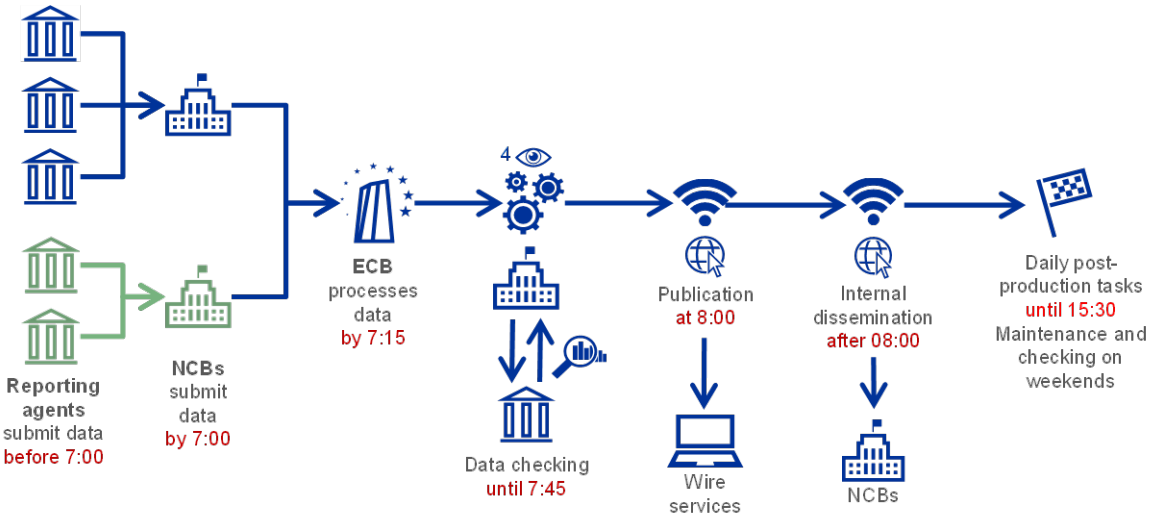

Figure 5.1.: Graphical representation of the €STR determination process. Source: ECB Economic Bulletin, Issue 4/2022 [27].

5.1.2. US Dollar area

In case of the US dollar area, the main reference rate here is LIBOR. Immediately prior to December 31, 2021, LIBOR was calculated for five currencies (USD, GBP, EUR, CHF and JPY) and for seven tenors in respect of each currency (Overnight/Spot Next, One Week, One Month, Two Months, Three Months, Six Months and 12 Months), resulting in the publication of 35 individual rates each applicable London business day [28]. Please note that the methodology described in Table 5.3 is applicable only to USD LIBOR.

[5]The money market statistical reporting (MMSR) dataset, collected on the basis of transaction-by-transaction data from a sample of euro area reporting agents, provides information on the secured, unsecured, foreign exchange swap and overnight index swap euro money market segments.

Long name	London Interbank Offered Rate
Definition	Average rate that is representative of the rates at which large, leading, internationally active banks with access to the wholesale, unsecured funding market could fund themselves in that market in US dollars for the relevant tenors.
Defined tenors	Overnight, 1 month, 3 months, 6 months and 12 months.
Administrator	ICE Benchmark Administration (IBA)
Life span	1984 - 2023.
Panel	Panel of credit institutions ("Contributor Banks") that are active participants in the US dollar money markets (for each tenor separately).
Replacement	SOFR
Computation	USD LIBOR is calculated using Contributor Bank submissions. Estimation approach follows a standardised, transaction data-driven Waterfall Methodology consisting of three levels: 1. Transaction-based: a volume weighted average price (cf. 5.1) of eligible transactions is estimated, where a Contributor Bank has sufficient eligible transactions. 2. Transaction-derived: in case a Contributor Bank has insufficient eligible transactions to make a Level 1 submission, it will seek to make a submission based on transaction-derived data, including time-weighted historical eligible transactions adjusted for market movements and linear interpolation. 3. Expert judgement: in case neither Level 1 nor Level 2 submission is possible, a Contributor Bank will submit the rate at which it could fund itself at 11:00 London time with reference to the unsecured, wholesale funding market. Then, Contributor Banks' submissions for each USD LIBOR tenor are ranked by IBA and the upper and lower quartiles are excluded to remove outliers. The relevant rate is then calculated as the arithmetic mean of the remaining submissions, rounded to five decimal places. Each panel bank's submission carries an equal weight, subject to the trimming.

Table 5.3.: LIBOR rate Summary. Source: ICE Benchmark Administration [28].

In 2017, the ARRC[6] selected SOFR as the rate for use in certain new USD derivatives and other financial contracts, representing the alternative to USD LIBOR. SOFR is a much more resilient rate than LIBOR because of how it is produced and the depth and liquidity of the markets that underlie it. As an overnight secured rate, SOFR better reflects the way financial institutions fund themselves today. The SOFR volumes are larger than the transactions in any other U.S. money market, therefore, it is a transparent rate that is representative of the market across a broad range of market participants. Also, the fact that it's derived from the U.S. Treasury repo market means that, unlike LIBOR, it's not at risk of disappearing. [29]
The rate is administrated by the Federal Reserve Bank of New York (NY FED). According to the NY FED homepage, the SOFR is calculated as a volume-weighted median of transaction-level tri-party repo data collected from the Bank of New York Mellon as well as GCF Repo transaction data and data on bilateral Treasury repo transactions.

5.2. Fallback rates

In the previous chapters we showed that IBORs play a major role in the functioning of financial markets. Therefore, it is highly important to define the replacement rates that would apply to derivatives trades referencing a particular benchmark, the so-called benchmark fallbacks. These would take effect if the relevant benchmark becomes unavailable while market participants continue to have exposure to that rate. [9] At the request of the FSB's Official Sector Steering Group, the International Swaps and Derivatives Association, Inc. (ISDA) is considering fallbacks for derivatives referencing EUR LIBOR, EURIBOR and other key interest rate benchmarks (ISDA IBOR fallbacks). In the euro area, fallback provisions, where present, were often originally intended to address the temporary unavailability of EURIBOR or EONIA, such as a computer failure affecting the designated screen page or a temporary market disruption, instead of their permanent cessation. Despite the unavailability of €STR until 2019, market participants might wanted to include a reference to it as

[6]The Alternative Reference Rates Committee (ARRC) is a group of private-market participants convened by the Federal Reserve Board and the New York Fed to help ensure a successful transition from U.S. dollar (USD) LIBOR to a more robust reference rate, its recommended alternative, the Secured Overnight Financing Rate (SOFR).

an alternative fallback in their new contracts for products that reference EONIA or EURIBOR. [30] According to the [31] and [30], the recommendations on EURIBOR fallbacks were set out:

- **Trigger event**: New contracts should include provisions covering both permanent and temporary cessation trigger events. The trigger events should be objective, so it is clear when they apply.
- **Fallback rate**: Identification of a reference rate as potential fallback rate.
- **Spread adjustment**: Application of an adjustment spread to the fallback rate to minimise the transfer of value.

According to the [32], the similar recommendations for fallbacks referencing US dollar LIBOR were set out. They include trigger events, replacement rates and spread adjustments.

6. Impact of the IBOR-reform on valuation of swaps

In this chapter, we aim to analyze the impact of the IBOR reform on financial markets in terms of the valuation of instruments and, in particular, on the valuation of swaps. Financial instruments can be categorized in several ways, depending on the criteria used for classification, such as

- Underlying asset
  - Equity instruments: stocks and equity derivatives,
  - Debt instruments: bonds and promissory notes.
- Cash flow characteristics
  - Fixed-income instruments: bonds and certificates of deposit,
  - Variable-income instruments: dividend-paying stocks,
  - Derivative instruments: options, futures, swaps and forwards.
- Level of risk volatility
  - Risk-free instruments: highly-rated government bonds,
  - Highly-risky or speculative instruments: certain types of equities or complex derivatives such as credit default swaps,
  - Hybrid instruments: convertible bonds.

For the purpose of this analysis, we would like to differentiate between linear and non-linear financial instruments based on their sensitivity to changes in the underlying asset. The key difference between the two types is the level of dependence on changes in the underlying asset for changes in the instrument value.

Using the simple terms, we may define a linear financial instrument as one whose payoff is a linear function. Linear derivative have a linear relationship with the underlying asset, meaning that their value changes in a predictable way based on the movements in the underlying asset, e.g., interest rates, exchange rates, commodity or stock prices. For example, a stock option contract with a linear payoff will increase in value by the same amount as the underlying stock increases. The main examples of linear financial instruments would be forwards, futures or swaps. In a practical part of this work, we aim to focus on swaps due to their overall materiality on financial markets.

6.1. Swaps - general information

In an interest rate swap, two parties (called counterparties) agree to exchange periodic interest payments. The amount of the interest payments exchanged is based on some predetermined principal, which is called the notional amount. The amount each counterparty pays to the other is the agreed-upon periodic interest rate times the notional amount. The only cash flows that are exchanged between the parties are the interest payments, not the notional amount. Accordingly, the notional principal serves only as a scale factor to translate an interest rate into a cash flow. In the most common type of swap, one party agrees to pay the other party fixed interest payments at designated dates for the life of the contract. This party is referred to as the fixed rate payer and the interest rate that this party agrees to pay is called the swap rate. The other party, who agrees to make interest rate payments that float with some reference rate, is referred to as the floating rate payer [33]. The exemplary graphical representation of how interest rate swaps work is given below:

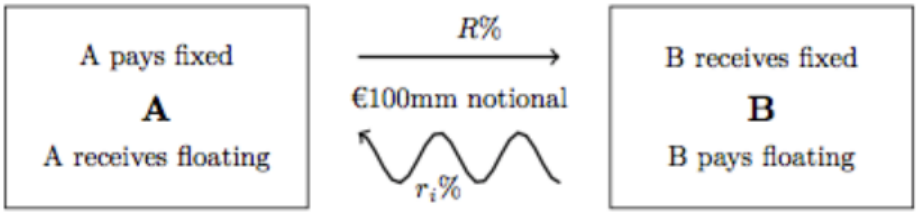

Figure 6.1.: Source: J.H.M Darbyshire - Pricing and Trading Interest Rate Derivatives: A Practical Guide to Swaps [34].

As already mentioned above, there are two counterparties participating in a swap market whose roles are:

Fixed Rate Payer	Floating Rate Payer
pays fixed rate in the swap	pays floating rate in the swap
receives floating in the swap	receives fixed in the swap
is short the bond market	is long the bond market
has bought a swap	has sold a swap
is long a swap	is short a swap
has established the price sensitivities of a longer-term liability and a floating rate asset	has established the price sensitivities of a longer-term asset and a floating rate liability

Table 6.1.: Source: Frank J. Fabozzi, Steven V. Mann "Introduction to Fixed Income Analytic: : Relative Value Analysis, Risk Measures, and Valuation" [33].

The reason to choose interest rate swaps for the further impact investigation is motivated mainly by volume of the product on financial market. According to the statistics provided by the CME Group, the total volume on USD interest rate swaps is $ 23 billion and $ 4.5 trillion of open interest (as of Oct 12, 2023).

6.2. Curves for swaps valuation

In our case study on the impact of the IBOR reform we will take EONIA and ESTR as well as corresponding OIS curves as basis of our investigation. In order to roughly estimate an impact of the IBOR reform on the valuation of interest rate swaps (IRS), we must firstly build discount and forward rate curves. Here we will follow these steps:

1. Obtain curves based on liquid linear interest rate derivatives with increasing maturities and which have ESTR and EONIA as underlying. In our analysis we are going to work with ESTR and EONIA based OIS[1] curves (see Table A.4 and Table A.3; Table A.6 and Table A.5 respectively) within a single-curve framework[2] which is a simplified view but might be useful for a rough estimation of the effect of the IBOR reform.

2. As a next crucial step we may need to perform bootstrapping of OIS par curves, i.e., implement a method for construction of zero rate curves[3]. This step is needed for estimation of OIS discount factors, which will be calculated according to the algorithm described in the following[4].
   Thereafter $\tau(t,T)$ denotes the time period in years between time point t and T according to a specific day count convention. We assume the Actual/360 one, as, in general, it is the most prevalent day count convention for money market instruments with maturity below one year. It is determined by the factor $\frac{1}{360}Days(t,T)$, i.e., one year is assumed to consist of 360 days.
   The crucial step in bootstrapping procedure is introduction of the concept of a simply compounded spot rate $R(t,T)$. By an arbitrage argument, one unit of currency at time T should be worth $P(t,T)$ units of currency at time t. Hence,

[1] Overnight indexed swap.

[2] Within the single-curve framework the same curve is used for both discounting and projecting cash-flows, i.e., estimation of forward rates. Multi-curve framework corresponds to the approach where different curves are used for calculation of forward rates with which the future cash flows are obtained and discounting of the future cash flows. Please note that in spite the differences in curves usage the economic pricing principle remains unchanged. Until the financial crisis of 2007–2008, the single-curve approach and its bootstrapping technique were used to value linear interest rate derivatives. Due to lessons learnt during the crisis, the valuation process for derivatives has been changed. [35] For the educational purposes of our analysis single-curve approach might be sufficient for the rough approximation of the impact of the IBOR reform.

[3] The par curve and the zero coupon curve are both representations of market interest rates, but they capture this information in slightly different ways. The par curve is constructed from the rates quoted on various market instruments, such as bonds or loans. These rates include both the interest payments (coupons) and the principal repayment. It provides a comprehensive view of the current market conditions by considering all the components of these instruments. On the other hand, the zero coupon curve focuses solely on the purest form of an interest rate: the interest rate without any intermediate coupon payments. It is derived from the par curve, but it isolates the impact of coupons. The zero coupon curve calculates the implied interest rates for different maturities, assuming that there are no coupon payments. [36]

[4] more detailed information on curve bootstrapping under the single- or multi-curve framework can be found in the paper *Valuation of Linear Interest Rate Derivatives: Progressing from Single to Multi-Curve Bootstrapping*. [35]

we want that the following equation holds:

$$1 = P(t,T)\big(1 + \tau(t,T)R(t,T)\big), \tag{6.1}$$

i.e., we assume that $R(t,T)$ is a risk-less lending rate. This leads to the definition of a simply compounded spot rate at time t for maturity T:

$$R(t,T) := \frac{1 - P(t,T)}{\tau(t,T)P(t,T)}. \tag{6.2}$$

In our analysis, simply compounded spot rates are market ESTR- and EONIA-based OIS rates. Using the bootstrapping technique, we are going to extract $N = 34$ distinct grid points of the zero-bond curve $P(0,\cdot)$ from the N distinct rates. These grid points will be the values $P(0,T)$ with

$$T \in \{1W, 2W, 1M, 2M, 3M, ..., 1Y, 2Y, 3Y, ..., 35Y, 40Y, 50Y\}.$$

To this end, different calculations will be applied - one for $T \leq 1y$ and one for $T > 1y$.

- **For** $T \leq 1y$:

$$P(0,T) = \frac{1}{1 + \tau(0,T)R(0,T)}. \tag{6.3}$$

- **For** $T > 1y$:

$$P(0,T) = P(0,T_n) = \frac{1 - R(0,T)\sum_{i=1}^{n-1}\tau(T_{i-1},T_i)P(0,T_i)}{1 + R(0,T)\tau(T_{n-1},T_n)}, \tag{6.4}$$

  where we write T_n to denote that the corresponding swap has a duration of n years and we put $T_0 := 0$.

In line with the above-described algorithm, discount rates (D) are estimated.To derive zero rates from discount factors, we will employ the following formula:

$$r_T = 100\Big(\big(\frac{1}{D(T)}\big)^{\frac{1}{\tau(0,T)}} - 1\Big) \tag{6.5}$$

3. Then, forward rates are estimated based on EONIA and ESTR OIS curves

according to the following formula:

$$F_{T_1,T_2} = \frac{1}{\Delta}\left(\frac{1}{D_{T_2}} \div \frac{1}{D_{T_1}} - 1\right), \tag{6.6}$$

Where:

- F_{T_1,T_2} is the forward rate between time T_1 and T_2.
- Δ is the time difference between T_1 and T_2.
- D_{T_1} and D_{T_2} are the discount factors at times T_1 and T_2, respectively.

In accordance with the steps outlined earlier, we have successfully estimated the curves. In the following, we present visual comparisons between the EONIA- and ESTR-based curves. The analyses were done based on data from February 2021 and December 2022.

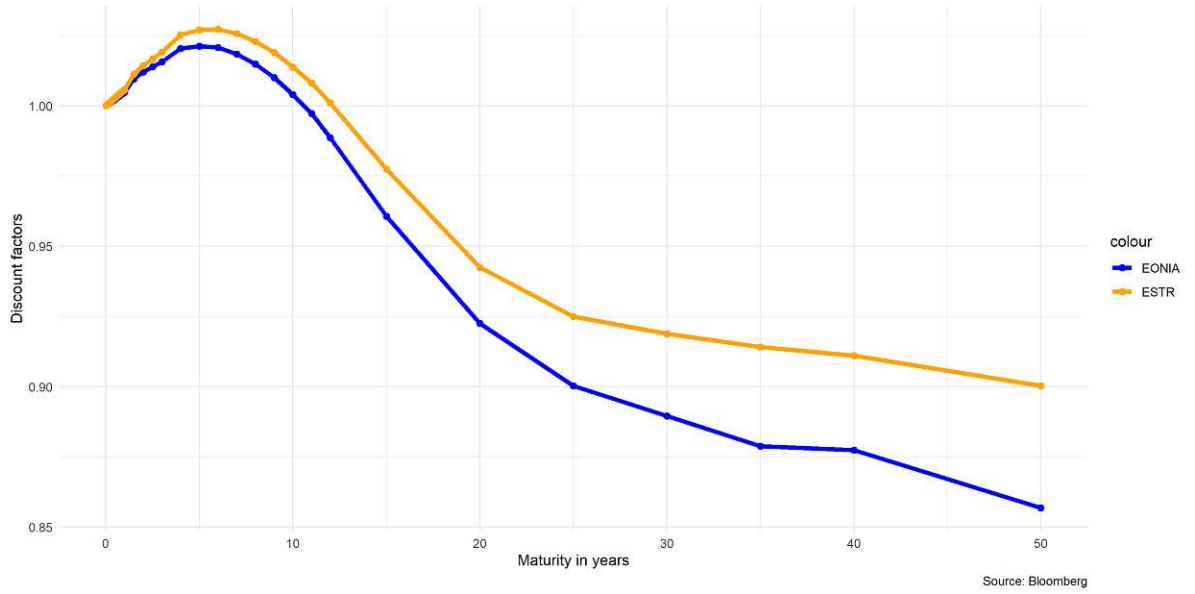

Figure 6.2.: A comparative illustration of discount factors derived from EONIA- and ESTR-based OIS curves as of February 2021.

Within Figure 6.3 and Figure 6.6, dedicated to the zero rate comparison, a distinct delta curve emerges. This curve signifies the disparity between the EONIA- and ESTR-based zero curves. Remarkably, this delta curve consistently maintains an

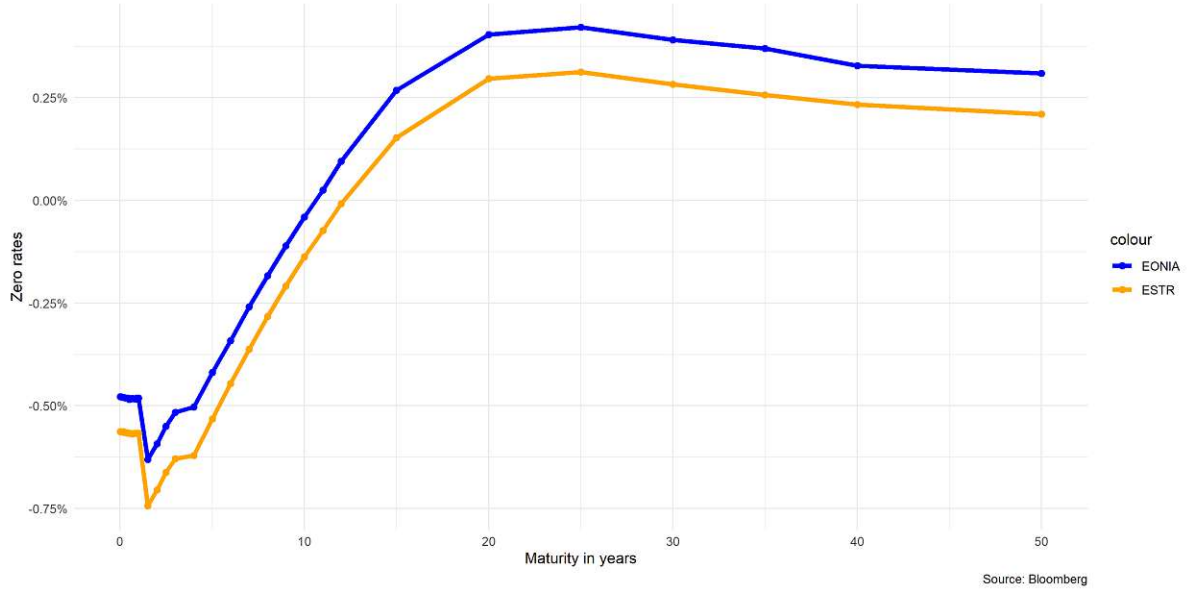

Figure 6.3.: A comparative illustration of zero rates derived from EONIA- and ESTR-based OIS curves as of February 2021.

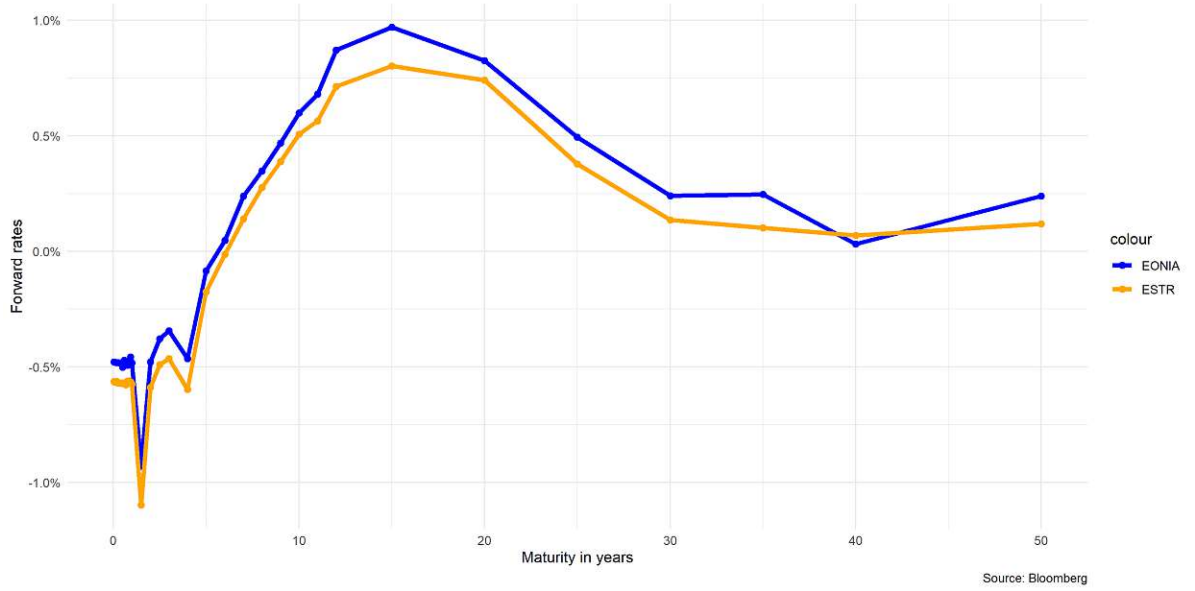

Figure 6.4.: A comparative illustration of forward rates derived from EONIA- and ESTR-based OIS curves as of February 2021.

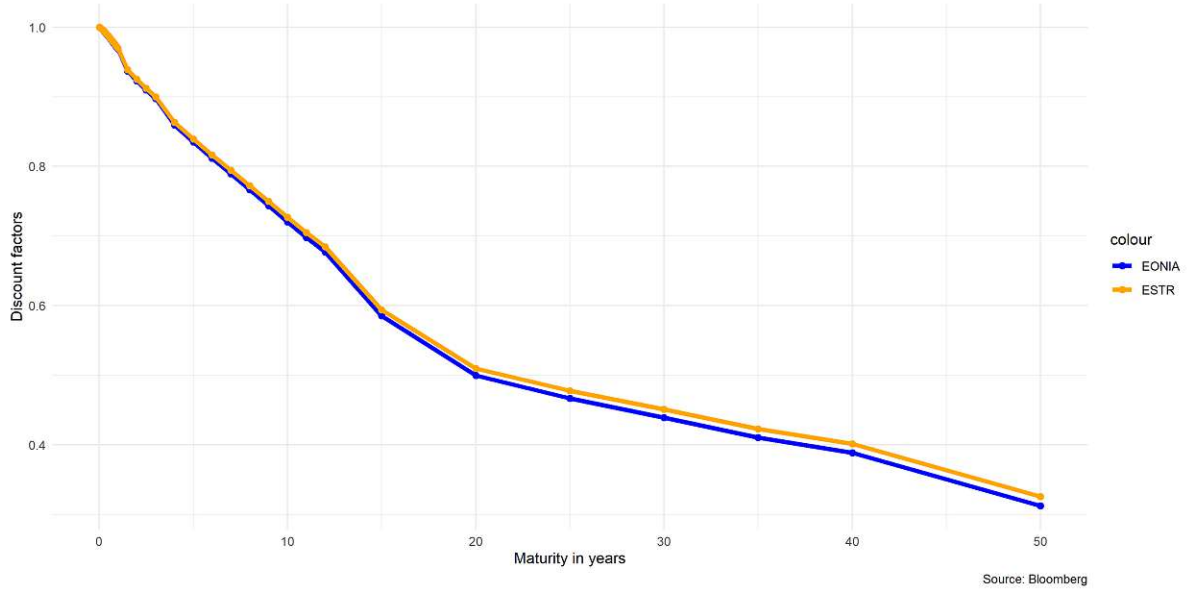

Figure 6.5.: A comparative illustration of discount factors derived from EONIA- and ESTR-based OIS curves as of December 2022.

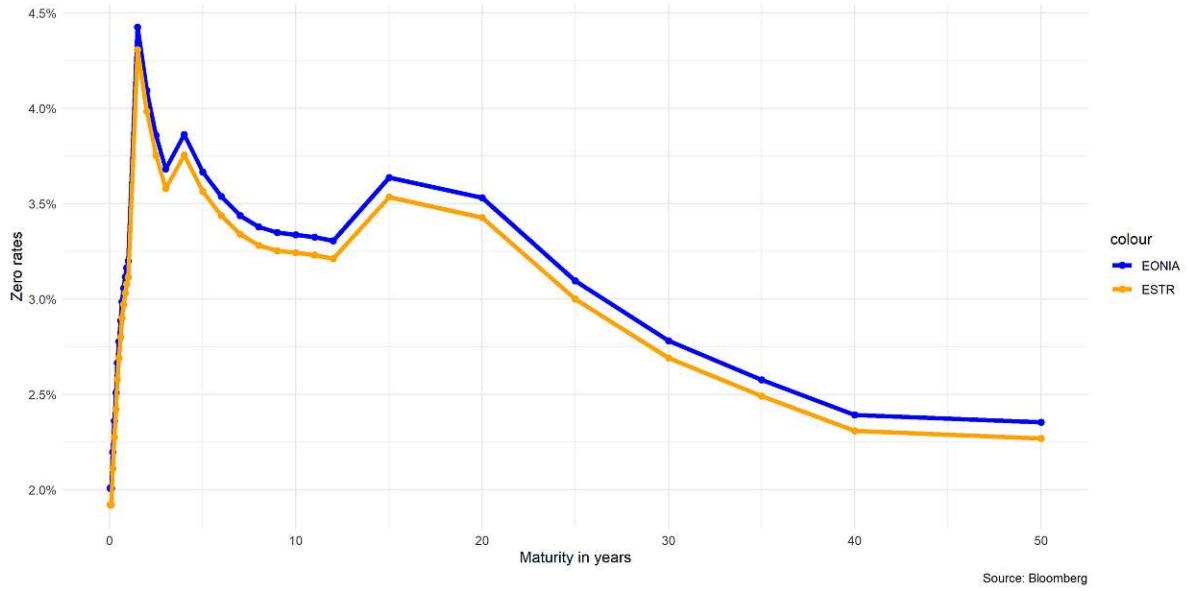

Figure 6.6.: A comparative illustration of zero rates derived from EONIA- and ESTR-based OIS curves as of December 2022.

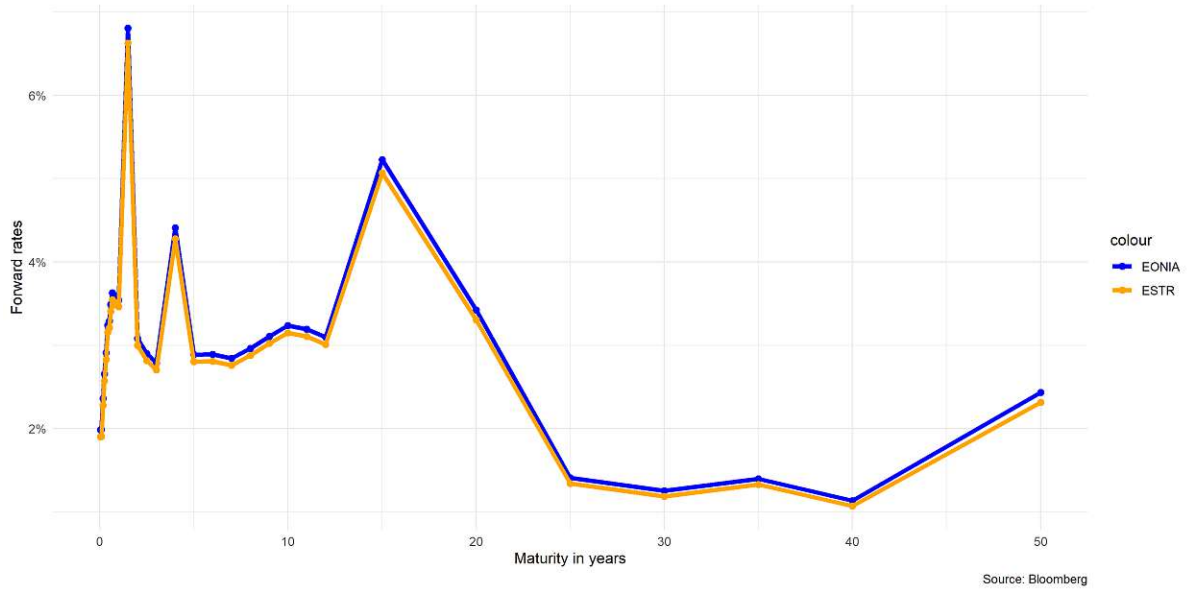

Figure 6.7.: A comparative illustration of forward rates derived from EONIA- and ESTR-based OIS curves as of December 2022.

approximate value of 8.5 basis points across diverse maturities. This consistency arises from the fixed spread established between the EONIA and ESTR curves, as outlined in 4.5. Although the delta curve generally adheres to this value, slight deviations may arise due to the bootstrapping process or effects from interpolation.

Both the zero and forward rate curves demonstrate that the ESTR-based curve consistently resides below the EONIA curve. This trend is vividly conveyed through the graphical representations featured in Figure 6.3, Figure 6.6, Figure 6.4 and Figure 6.7.

6.3. Swaps valuation and impact estimation

In this subsection we will evaluate the swaps using curves described in the previous subsection. For the purpose of our analysis we simulated an interest rate swap portfolio with the following characteristics:

- Portfolio size: 100 interest rate swaps.
- Swap types: Plain vanilla interest rate swaps (IRS).

- Notional amount: €10 Million.
- Swap maturities: Range of maturities, extending from 1 year to 10 years. This approach allows us to assess a broad variety of swaps.
- Swap rates: random simulation of rates in a range between 0% and 5%.
- Fixed leg direction: random determination of the direction of each swap's fixed leg, either "pay" or "receive".

The present value of a fixed rate leg is calculated as follows [37] .

$$PV_{fixed}(t) = SR \cdot NA \cdot \sum_{i=1}^{n} \tau_i D_i, \tag{6.7}$$

where SR denotes to a swap rate, t is a valuation date, NA is a notional amount, τ_i is a time period in years and $D_i = D(t, T_i)$ is a discount factor.
The present value of a floating leg is given by

$$PV_{float}(t) = NA \cdot \sum_{i=1}^{n} F_i \tau_i D_i, \tag{6.8}$$

where F_i denotes to a forward rate.
The present value of an interest rate swap can be expressed as

- From the fixed rate payer perspective, $PV = PV_{float} - PV_{fixed}$,
- From the fixed rate receiver perspective, $PV = PV_{fixed} - PV_{float}$.

Following the procedure described above, the interest rate swaps were valuated based on curves as of February 2021 and December 2022. In the following charts, the impact calculations are presented in basis points[5] relative to the notional amount.

On both charts, the X-axis represents the maturities of interest rate swaps, ranging from one to ten years. The Y-axis measures the impact of the IBOR reform on the interest rate swaps. The impact from the change of interest rates is quantified in basis points in relation to the notional amount.
The charts provide a visual comparison of how differences in interest rates impact

[5] A basis point (often abbreviated as bp) is one hundredth of 1 percentage point.

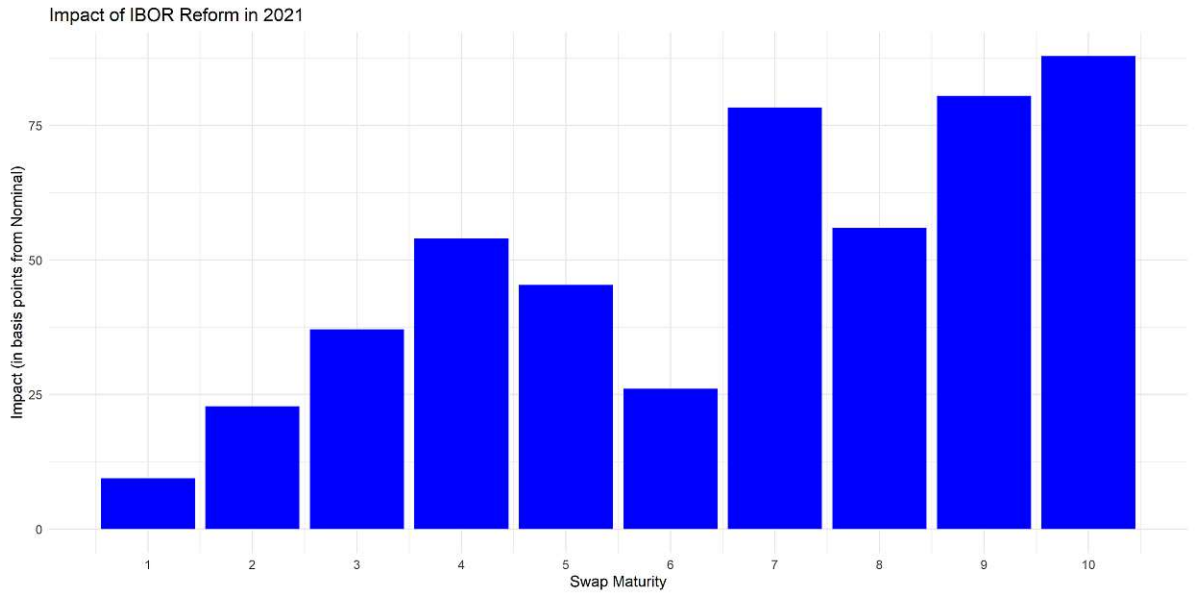

Figure 6.8.: Impact of IBOR Reform on IRS valuation in 2021 in Basis Points (bps) from Nominal Amount.

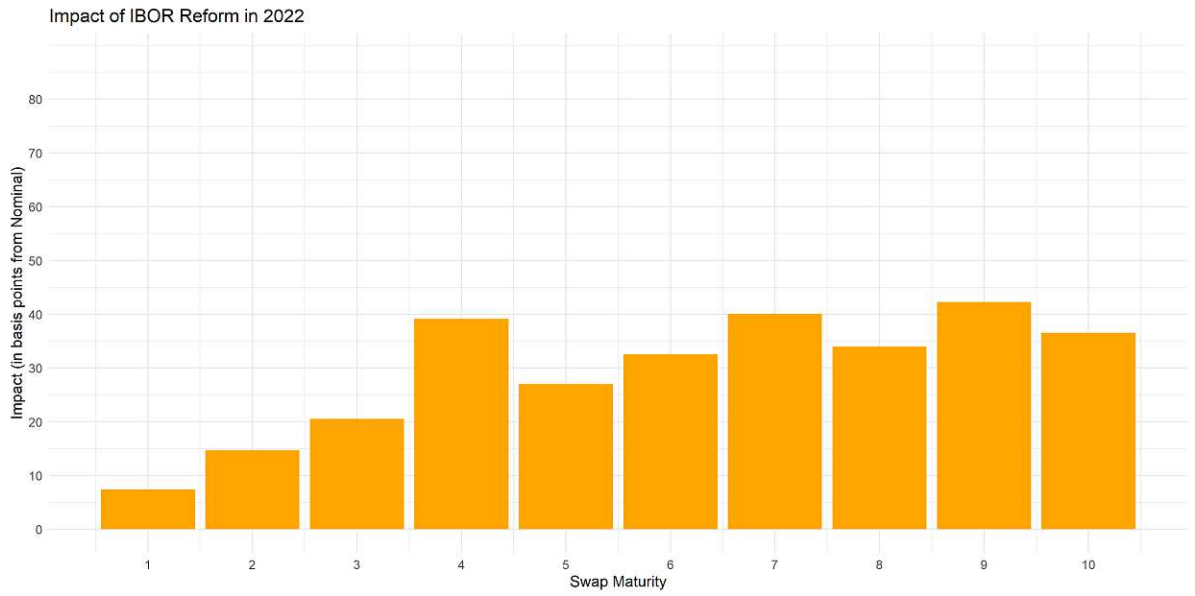

Figure 6.9.: Impact of IBOR Reform on IRS valuation in 2022 in Basis Points (bps) from Nominal Amount.

the valuation of interest rates swaps. Despite the fact that the impact in 2022, ranging between 5 and 45 basis points (bps) from the notional amount, is relatively lower compared to 2021, where more than half of the years experienced impacts exceeding 50 bps, it is evident that the IBOR reform has significantly reshaped the swap market. These substantial changes underscore the profound influence of the reform on interest rate swaps.

6.4. Overall impact on swaps market

In November 2020, the ECB published their Financial Stability Review, where, among others, statistics on transition to the new euro benchmark were provided. The immense notional amounts of the OIS contracts (as presented on the Figure 6.10) make Overnight index swaps (OISs) the main product in the short-term interest rate derivatives markets. They are essential for managing interest rate risk, and therefore helping to support the stability of the financial system. [38]

In 2022, the ECB provided update on the progress of the transition to €STR (see [27]

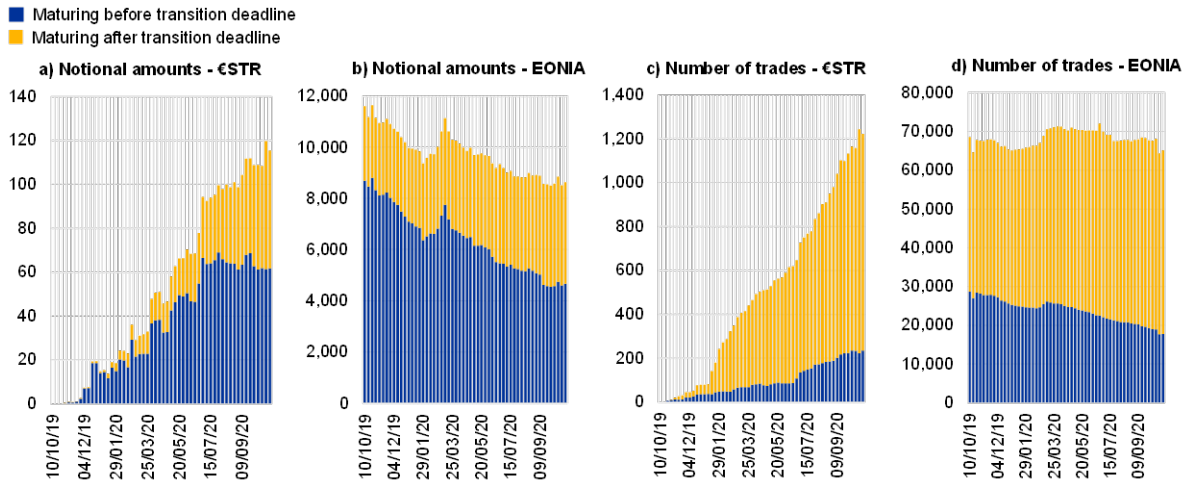

Figure 6.10.: Source: ECB. Amount and number of OIS contracts by reference rate and by maturity (EUR billions (a) and (b); number of trades (c) and (d)). [38]

for more details).

The main market to transition was the overnight index swap market, where €STR swaps slowly started being traded in October 2019, supported by clearing infrastructure. As shown on the Figure A.1, the transition from EONIA to €STR accelerated a lot in 2021. In 2021, the amount of EONIA and €STR transactions reached €1 TN.

Extrapolating the results provided in the section 6.3, we see that the overall impact of the IBOR reform on a swap market can be measured in billions of euros.

7. Conclusion

The IBOR reform has left a profound impact on the financial landscape. As we have explored in this thesis, this reform was initiated with the objective of transitioning from Interbank Offered Rates (IBORs) to alternative reference rates (ARRs) that have greater reliability, robustness, frequency, availability, and representativeness. The journey through this transformation has been accompanied by significant changes in how interest rates are calculated and applied in financial markets.

Throughout this study, we have traced the historical context of the IBOR reform, delved into its motivations, and investigated implications. Additionally, we have studied the milestones of this reform, which reflect the global change in the direction of a more resilient and transparent financial system.

The comparison between IBORs and ARRs in the euro and US dollar areas revealed the critical distinctions between the old and the new reference rates. Governance frameworks and estimation methodologies have undergone significant transformations to adapt to the new financial landscape.

In the practical part of this thesis, we investigated the impact of the IBOR reform within the euro area and observed a substantial effect on the interest rate swap market.

In conclusion, the IBOR reform has brought a huge shift in the financial industry. The transition to ARRs has led to changes in pricing, risk management, and market behavior. It has required market participants to adapt, innovate, and reevaluate their strategies. The lessons learned from this reform will shape the future of financial markets for years to come.

A. Appendix

A.1. Interbank Offered Rates (IBORs) and Alternative Reference Rates (ARRs)

A.2. Overview milestones of the IBOR reform

Currency	IBOR	ARR	Administrator	Type of ARR
AUD	BBSW	Interbank Overnight Cash Rate (AONIA)	Reserve Bank of Australia	Unsecured
BRL	DI Rate	Selic	Central Bank of Brazil	Secured
CAD	CDOR	Canadian Overnight Repo Rate Average (CORRA)	Bank of Canada	Secured
CHF	LIBOR	Swiss Average Rate Overnight (SARON)	SIX Swiss Exchange	Secured
GBP	LIBOR	SONIA	Bank of England	Unsecured
HKD	HIBOR	HONIA	Treasury Market Association	Unsecured
JPY	LIBOR	TONA or TIBOR	Japan's Bankers Association	Unsecured
JPY	TIBOR	TONA		Unsecured
JPY	Euroyen TIBOR	TONA		Unsecured
SGD	SOR	SORA	ABS Association of Banks in Singapore	Unsecured
TRY	TRLIBOR	TLREF	Borsa Istanbul	Secured
ZAR	JIBAR	Preferred alternative rate is ZARONIA		Unsecured

Table A.1.: Mapping of major interest rate benchmarks to alternative reference rates [21]

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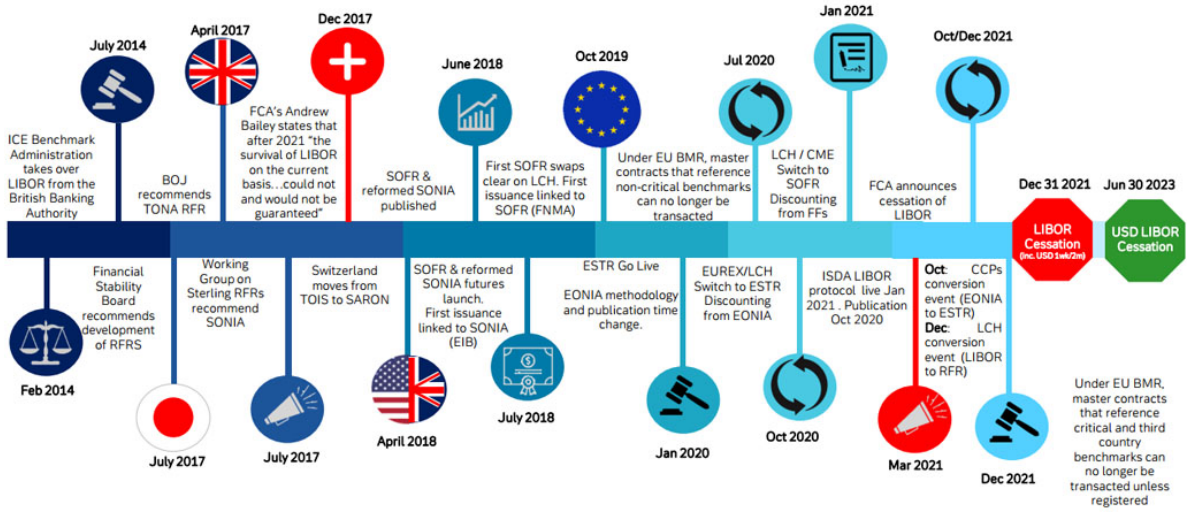

Table A.2.: Milestones of the IBOR reform [39].

A.3. Overview transition from EONIA to €STR

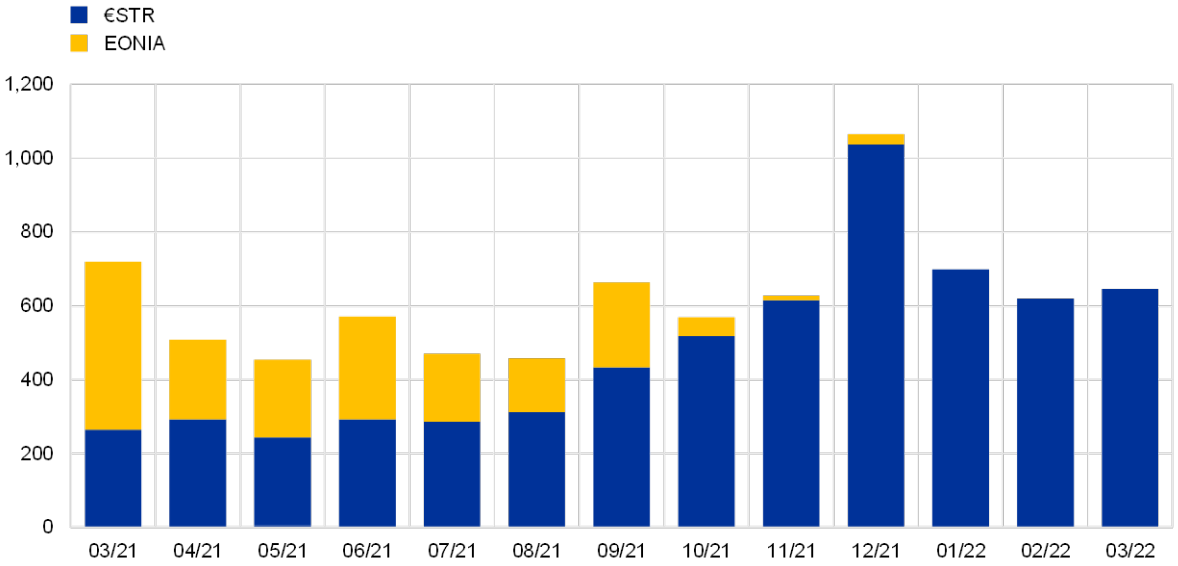

Figure A.1.: Source: ECB. Shares (in EUR billions) of the €STR and EONIA OIS in MMSR transactions [27].

	EONIA			
Tenor	OIS Par rate in %	Discount factor	Zero rate in %	Forward rate in %
1W	-0.479%	1.000092124	-0.478%	
2W	-0.479%	1.000184265	-0.478%	-0.479%
1M	-0.480%	1.000399743	-0.478%	-0.480%
2M	-0.481%	1.000801475	-0.480%	-0.482%
3M	-0.481%	1.001203948	-0.480%	-0.482%
4M	-0.482%	1.00160758	-0.481%	-0.484%
5M	-0.482%	1.002011329	-0.481%	-0.484%
6M	-0.485%	1.002430895	-0.484%	-0.502%
7M	-0.483%	1.002825461	-0.483%	-0.472%
8M	-0.482%	1.003223692	-0.482%	-0.476%
9M	-0.483%	1.00363567	-0.483%	-0.493%
10M	-0.484%	1.004045467	-0.483%	-0.490%
11M	-0.481%	1.004428694	-0.481%	-0.458%
1Y	-0.481%	1.004833248	-0.481%	-0.483%
18M	-0.479%	1.009532963	-0.631%	-0.931%
2Y	-0.479%	1.011956599	-0.593%	-0.479%
30M	-0.462%	1.013874302	-0.550%	-0.378%
3Y	-0.445%	1.015623538	-0.515%	-0.344%
4Y	-0.404%	1.020357871	-0.503%	-0.464%
5Y	-0.350%	1.021226212	-0.419%	-0.085%
6Y	-0.293%	1.020747479	-0.342%	0.047%
7Y	-0.226%	1.018304543	-0.259%	0.240%
8Y	-0.162%	1.014764875	-0.183%	0.349%
9Y	-0.099%	1.010022902	-0.111%	0.469%
10Y	-0.036%	1.004006134	-0.040%	0.599%
11Y	0.023%	0.997211167	0.025%	0.681%
12Y	0.087%	0.988590862	0.096%	0.872%
15Y	0.219%	0.96063902	0.268%	0.970%
20Y	0.316%	0.922557515	0.404%	0.826%
25Y	0.344%	0.900283173	0.421%	0.495%
30Y	0.330%	0.889593552	0.391%	0.240%
35Y	0.320%	0.878784032	0.370%	0.246%
40Y	0.290%	0.877405806	0.327%	0.031%
50Y	0.259%	0.856910634	0.309%	0.239%

Table A.3.: EONIA rates as of February 2021

	ESTR			
Tenor	OIS Par rate in %	Discount factor	Zero rate in %	Forward rate in %
1W	-0.564%	1.000108473	-0.562%	
2W	-0.564%	1.000216951	-0.562%	-0.564%
1M	-0.565%	1.000471055	-0.564%	-0.566%
2M	-0.564%	1.000940884	-0.563%	-0.563%
3M	-0.566%	1.001417005	-0.565%	-0.571%
4M	-0.567%	1.001891906	-0.565%	-0.569%
5M	-0.568%	1.002370188	-0.567%	-0.573%
6M	-0.568%	1.002845574	-0.567%	-0.569%
7M	-0.568%	1.003324348	-0.567%	-0.573%
8M	-0.569%	1.003807778	-0.568%	-0.578%
9M	-0.568%	1.004278225	-0.568%	-0.562%
10M	-0.567%	1.004747432	-0.567%	-0.560%
11M	-0.567%	1.005220024	-0.566%	-0.564%
1Y	-0.567%	1.005702332	-0.567%	-0.575%
18M	-0.565%	1.01125306	-0.743%	-1.098%
2Y	-0.570%	1.014241739	-0.705%	-0.589%
30M	-0.557%	1.016735942	-0.662%	-0.491%
3Y	-0.543%	1.019100323	-0.629%	-0.464%
4Y	-0.500%	1.025233195	-0.621%	-0.598%
5Y	-0.445%	1.027035133	-0.532%	-0.175%
6Y	-0.382%	1.027162257	-0.446%	-0.012%
7Y	-0.316%	1.025728434	-0.362%	0.140%
8Y	-0.250%	1.022900023	-0.283%	0.277%
9Y	-0.186%	1.018948078	-0.208%	0.388%
10Y	-0.123%	1.013805091	-0.137%	0.507%
11Y	-0.066%	1.008103826	-0.073%	0.566%
12Y	-0.007%	1.000956734	-0.008%	0.714%
15Y	0.125%	0.977418463	0.152%	0.803%
20Y	0.232%	0.942518403	0.296%	0.741%
25Y	0.255%	0.925029997	0.312%	0.378%
30Y	0.239%	0.91880122	0.283%	0.136%
35Y	0.222%	0.914170779	0.257%	0.101%
40Y	0.206%	0.911060213	0.233%	0.068%
50Y	0.176%	0.900374092	0.210%	0.119%

Table A.4.: ESTR rates as of February 2021

	EONIA			
Tenor	OIS Par rate in %	Discount factor	Zero rate in %	Forward rate in %
1W	1.988%	0.99961779	2.008%	
2W	1.988%	0.999236161	2.007%	1.986%
1M	1.989%	0.998345326	2.007%	1.989%
2M	2.178%	0.996383377	2.198%	2.363%
3M	2.341%	0.994182294	2.361%	2.657%
4M	2.488%	0.99177488	2.509%	2.913%
5M	2.644%	0.989104601	2.664%	3.240%
6M	2.758%	0.986397821	2.777%	3.293%
7M	2.870%	0.983536259	2.887%	3.491%
8M	2.972%	0.980570005	2.987%	3.630%
9M	3.046%	0.97766703	3.057%	3.563%
10M	3.109%	0.974747936	3.117%	3.594%
11M	3.160%	0.971850945	3.164%	3.577%
1Y	3.200%	0.968989901	3.200%	3.543%
18M	3.274%	0.937112178	4.425%	6.803%
2Y	3.237%	0.922885974	4.094%	3.083%
30M	3.183%	0.909694609	3.858%	2.900%
3Y	3.129%	0.897190112	3.682%	2.787%
4Y	3.063%	0.859297919	3.864%	4.410%
5Y	3.036%	0.835182065	3.668%	2.887%
6Y	3.017%	0.811708682	3.538%	2.892%
7Y	2.998%	0.789265376	3.439%	2.844%
8Y	2.994%	0.766558732	3.379%	2.962%
9Y	3.004%	0.743464906	3.349%	3.106%
10Y	3.022%	0.720164377	3.337%	3.235%
11Y	3.034%	0.697879519	3.324%	3.193%
12Y	3.038%	0.676916483	3.305%	3.097%
15Y	3.019%	0.585137668	3.637%	5.228%
20Y	2.874%	0.499575081	3.531%	3.425%
25Y	2.701%	0.466673789	3.095%	1.410%
30Y	2.556%	0.439177849	2.781%	1.252%
35Y	2.457%	0.410473201	2.577%	1.399%
40Y	2.358%	0.388431012	2.392%	1.135%
50Y	2.218%	0.312378704	2.354%	2.435%

Table A.5.: EONIA rates as of December 2022

	ESTR			
Tenor	OIS Par rate in %	Discount factor	Zero rate in %	Forward rate in %
1W	1.903%	0.999634124	1.921%	
2W	1.903%	0.999268804	1.920%	1.901%
1M	1.904%	0.99841593	1.921%	1.904%
2M	2.093%	0.996524041	2.111%	2.278%
3M	2.256%	0.994392373	2.275%	2.572%
4M	2.403%	0.99205365	2.422%	2.829%
5M	2.559%	0.989451213	2.578%	3.156%
6M	2.673%	0.986811511	2.691%	3.210%
7M	2.785%	0.984016134	2.801%	3.409%
8M	2.887%	0.981115168	2.901%	3.548%
9M	2.961%	0.978276753	2.972%	3.482%
10M	3.024%	0.975421413	3.031%	3.513%
11M	3.075%	0.972587421	3.079%	3.497%
1Y	3.115%	0.969788659	3.115%	3.463%
18M	3.189%	0.938694878	4.308%	6.625%
2Y	3.152%	0.92483083	3.985%	2.998%
30M	3.098%	0.911991872	3.754%	2.816%
3Y	3.044%	0.899830487	3.581%	2.703%
4Y	2.978%	0.86290653	3.755%	4.279%
5Y	2.951%	0.8393794	3.564%	2.803%
6Y	2.932%	0.816459319	3.437%	2.807%
7Y	2.913%	0.794537021	3.340%	2.759%
8Y	2.909%	0.772315325	3.282%	2.877%
9Y	2.919%	0.749669417	3.253%	3.021%
10Y	2.937%	0.726780219	3.243%	3.149%
11Y	2.949%	0.704877072	3.230%	3.107%
12Y	2.953%	0.684270269	3.212%	3.012%
15Y	2.934%	0.593939402	3.534%	5.070%
20Y	2.789%	0.509729628	3.427%	3.304%
25Y	2.616%	0.477662545	3.000%	1.343%
30Y	2.471%	0.450905376	2.691%	1.187%
35Y	2.372%	0.422764809	2.490%	1.331%
40Y	2.273%	0.401254285	2.309%	1.072%
50Y	2.133%	0.325837654	2.268%	2.315%

Table A.6.: ESTR rates as of December 2022

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