The Clock Is Ticking:
A Multi-Maturity Clock Auction Design for "IBOR" Transition

PRELIMINARY DRAFT

Haoxiang Zhu[1]
MIT Sloan School of Management and NBER
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This paper proposes a "clock auction" mechanism that converts cash flows linked to existing "IBOR" reference rates (or benchmarks) to cash flows linked to new reference rates. The auction design will also discover market-clearing spreads between IBORs and new reference rates across maturities, hence improving liquidity in markets for the new reference rates.

The most widely used reference interest rates in financial markets are collectively known as "IBORs", or interbank offered rates, which are estimates of the borrowing costs of large banks. Prominent examples include LIBOR (L for London), EURIBOR (EUR for Euro), and TIBOR (T for Tokyo), among others. Following the widespread and highly publicized scandals of manipulation in IBORs, authorities in many jurisdictions have chosen their preferred replacement reference rates. The following table summarizes the officially preferred new reference rates in the US, the UK, Japan, Switzerland, and the Eurozone.

Jurisdiction (currency)	**New reference rate**	**Properties**
US (USD)	SOFR (secured overnight financing rate)	This new rate is based on overnight secured (repo) transactions and published by the NY Fed since April 2018. [link]
UK (GBP)	SONIA (Sterling overnight index average)	Reformed SONIA is based on unsecured transactions; it is administered and published by BoE since April 2016. [link]
Japan (JPY)	Overnight call rate	It is an existing unsecured rate, published by Bank of Japan. [link]
Switzerland (CHF)	SARON (Swiss average rate overnight)	It is based on overnight secured (repo) transactions and published jointly by SNB and Six Swiss Exchange since 2009. [link]
Eurozone (EUR)	ESTER (Euro short-term rate)	ECB announced the methodology of the new reference rate (it is unsecured) and plans to publish it in October 2019. [link]

Table 1: New reference rates in major jurisdictions

[1] I first presented the clock auction design for IBOR conversion at the Benchmark Forum NY on June 7, 2018. I thank Darrell Duffie for our research collaboration on financial benchmarks as well as numerous discussions related to IBOR transition. I also thank Lee Betsill (and CME colleagues), David Bowman, Songzi Du, Fabian Eser, Bill Goulding, Hicham Hajhamou, Antoine Lallour, Eric Litvack, Mark Manning, Matt Pritsker, Sayee Srinivasan, and Bruce Tuckman for helpful comments and suggestions.

The most important difference between the new reference rates and the existing IBORs is that the new reference rates are based on much larger underlying transaction volume, hence more robust to manipulation. For example, in the United States, the Alternative Reference Rate Committee (ARRC) find that various types of repo markets that underlie SOFR have over $700 billion of daily transaction volume, whereas unsecured lending based on LIBOR has less than $1 billion of daily transaction volume.

The scarcity of underlying transactions makes IBORs inherently unstable and their future highly uncertain. For example, after the end of 2021, the UK FCA will no longer compel banks to submit to the LIBOR panel. Given the litigation risk associated with IBOR submissions, there is indeed a nontrivial a chance that banks will eventually stop submission, spelling the end to LIBOR and other IBORs. Currently, however, hundreds of trillions of dollars of derivatives and trillions of dollars of floating rate bonds and loans are linked to IBORs, especially LIBOR and EURIBOR. Therefore, a successful transition from IBORs to new reference rates must address these legacy securities and derivatives, in addition to building sufficient liquidity in markets based on new reference rates.

The liquidity in markets linked to the new reference rates is developing as we speak. The table below summarizes recent progress in SOFR (US) and SONIA (UK). As we can see, while these developments are definitely positive and promising, this new market has a long way to go before catching up with the depth of liquidity in IBOR-linked derivatives and cash products. Simultaneously, the ARRC and ISDA are coordinating efforts to come up with more robust replacement language in IBOR-linked contracts.

	Futures contracts	**Swaps**	**Debt issuance**
SOFR (USD)	CME SOFR futures are liquid up to June 2020 maturity.	Only a handful of trades so far, with maturity up to 2 years (mostly one year)	Fannie Mae, World Bank, Credit Suisse, and MetLife issued SOFR-linked debt with maturity up to 2 years.
SONIA (GBP)	ICE and CurveGlobal launched SONIA futures; CME will launch.	Liquid and large volume, although maturity is mostly less than a year	Lloyds issued SONIA-linked debt with maturity of 3 years.

Table 2: Current liquidity in derivatives and cash products linked to new reference rates

This paper proposes an auction mechanism that helps the transition away from IBOR into new reference rates, focusing on the economic (cash flows) rather than the legal aspect. The details are spelled out in Section 1. In the event that organic liquidity in the new reference rates fails to develop sufficiently fast, an organized auction could be used as a “catalyst” mechanism to speed up the transition. Even if the markets for derivatives and cash products indexed to new reference rates become liquid very soon, auctions may still be used for the relatively illiquid segment of these markets, or serve as a backstop.

An important benefit of auctions is that they are coordinated. The transition away from IBORs requires substantial investments in technology, legal documentation, and client engagement. “I move only if you move" is too strong a temptation, potentially leading to a deadlock or slow progress. In a coordinated auction, many participants act together, mitigating the perceived first-mover disadvantage.

At a fundamental level, auction design is not meant to replace the market, but help the market deliver its best. Auctions are widely used already. In addition to obvious examples like Treasury auctions, market mechanisms such as limit order books are essentially continuous double auctions. Reverse auctions are also used successfully in the U.S. and the UK for implementing Quantity Easing operations. The answer to "why not leave the problem to the market?" is that "auction is a form of the market." Dealer banks, exchanges, clearinghouses, technology venders, asset managers, insurance companies, pensions, nonfinancial corporations, and the official sector are all stake holders. The official sector, in particular, plays the unique role as regulators and supervisors of reference rates, setting the market expectation for the direction and the pace of IBOR transition, as they did in a series of speeches and reports over the last few years.

To the best of my knowledge, Duffie (2017, 2018) is the first to propose the use of auctions for IBOR transition. His "compression auction" design takes advantage of the widely used trade compression services in derivatives markets. I discuss the commonalities and the differences between his method and mine in Section 2.

1. The Multi-Maturity Clock Auction

The problem we want to solve is to convert IBOR cash flows to cash flows linked to the new reference rate. Because a new reference rate is typically different from IBOR in expectation, market participants would demand compensation, or a spread, to do the conversion. Finding the right spread, maturity by maturity, is the key step for converting IBOR contracts to those using the new reference rate.

Figure 1 below illustrates this point. In this example, the entity doing the conversion is assumed to receive IBOR, but the opposite direction is entirely symmetric. The top chart shows the conversion of an IBOR-based interest rate swap. For example, because USD overnight repo rate is generally lower than USD LIBOR, a market participant receiving 3-month LIBOR would demand to receive quarterly-compounded overnight SOFR plus a positive spread, denoted y basis points, to do the LIBOR-to-SOFR conversion. Likewise, the bottom chart shows the conversion of an IBOR-based floating rate loan.

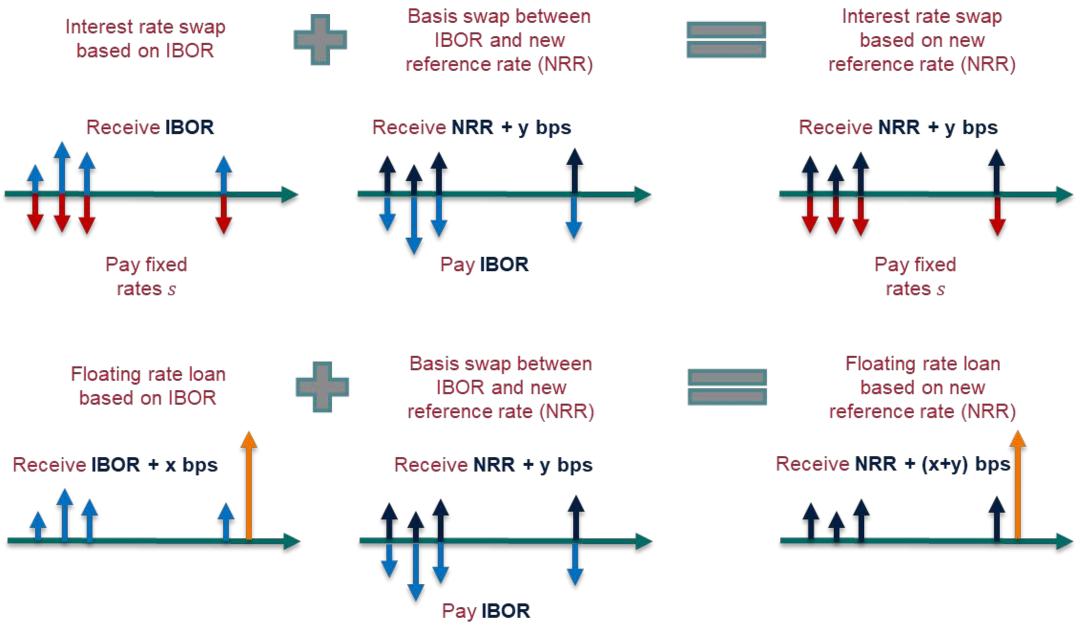

Figure 1: Illustration of IBOR conversion in swaps and cash products

In both charts, the middle piece, namely the basis swap between IBOR and the corresponding new reference rate, is the main outcome from the auction. Not only does the auction discover the spread (y basis points) between IBOR and the new reference rate, it also produces transactions in the basis swaps themselves. (I will discuss how the basis swap may be handled post-auction.)

Many choices in the auction design presented subsequently are motivated by the following two general "principles," inspired by the extensive experience of auctions in other markets, especially the spectrum auctions in the U.S. and other countries. See Milgrom (2004)[2] for a detailed discussion and analysis.

Principle 1: Respect the Law of One Price. Auction participants should pay identical prices for identical cash flows, and pay similar prices for similar cash flows.

Principle 2: Simplify bidders' strategies. Auction participants should be able to come up with effective bidding strategies without burdensome guesswork, regardless of their level of sophistication or financial resources.

These two principles are intuitive, yet powerful. We will return to them in the discussion of the auction design.

Now, let's go through the auction design step by step. For concreteness, I will occasionally refer to LIBOR versus SOFR in the description of the mechanism, but the general procedure works for any new reference rate.

[2] Paul Milgrom, *Putting Auction Theory to Work*, Cambridge University Press, 2004.

Step 1. Start of the auction

The auction starts by displaying a customized maturity grid as well as an initial spread between IBOR and the new reference rate on each maturity. The spreads are displayed to all participants throughout the auction—as if on digital clocks, hence the name clock auction. As we make it more evident later, the main point of displaying the prices is to induce the law of one price by encouraging the arbitrage of "mispricing" across maturities.

The maturity grid is chosen by the auctioneer, and can be made as dense or as sparse as needed. For example, a dense maturity grid could mimic the convention in the futures market, with one month interval in very short maturities and one quarter interval in longer maturities. Conversely, a sparse maturity grid may just take the standard maturities in government bond or swaps markets. Ultimately, the choice of the maturity grid should follow the maturity structure of swaps and cash products.

To keep the graphs simple, the table below illustrates a simple grid with only four standard maturities. Again, the actual implementation probably needs a (much) denser grid.

Maturity	2y	5y	7y	10y
Spread (bps)	0	0	0	0

Table 3.1: Starting position of the auction

The starting spreads on these maturities are deliberately set too low so that there would be excessive demand to pay the spread. In the LIBOR versus SOFR conversion, for example, because LIBOR is higher than SOFR on average due to the credit risk component in LIBOR, the vast majority of players would be happy to receive LIBOR and pay SOFR plus a zero spread. As we show in the next step, this excess demand to pay the spread, which we label as the supply, will push the spread up in subsequent rounds of the auction across the maturities.

The choice of starting at too low a spread, rather than too high a spread, is for simplicity and familiarity. It is probably more familiar to bidders if the price in an auction goes up rather than goes down.

Step 2. Bidding

The auctioneer solicits participants to submit demand or supply anonymously, maturity by maturity, at the currently displayed spreads. Here, demand means paying LIBOR and receiving SOFR plus spread, and supply means paying SOFR plus spread and receiving LIBOR. Since SOFR is overnight but the most popular LIBOR maturities are 3 months or 6 months, we use the convention that overnight SOFR is compounded into the LIBOR maturity, say 3 months. As I alluded above, at the starting position of Table 3.1, there should be excess supply because the spread is deliberately started at too low a level. Table 3.2 below shows hypothetical demand and supply, in terms of notional amount, at the four example maturities at the initial spread of zeros.

Maturity	2y	5y	7y	10y
Spread (bps)	0	0	0	0
Demand ($bn notional)	0	0	0	0
Supply ($bn notional)	100	200	200	250

Table 3.2: Submitted demand and supply at the initial position of the auction

To be precise, this hypothetical example says that, at the 2-year maturity, auction participants collectively wish to receive 3-month LIBOR and pay quarterly compounded SOFR plus zero spread for $100 billion notional amount. No one wishes to trade the basis swap in the opposite direction. This supply-demand imbalance means that the market will not clear at the current spreads and that the spreads should move up, as I discuss in the following two steps.

In the baseline design, the actual demand and supply are displayed together with the spreads. A variant of this design may only show the net demand (demand minus supply), or just the sign of the imbalance. A good reason to disclose some information about supply and demand is to attract liquidity providers to where the imbalance is largest (hence largest price dislocation and largest profits for correcting them). Conversely, the main reason not to disclose too much information about supply and demand is to minimize the risk of “spoofing”.[3]

Discussion. Before moving on, let me make a few remarks on this process of bidding. Firstly, an auction participant here only needs to indicate the side and quantity, but not the price. Market participants who are well informed of the going prices on the market may or may not wish to reveal this knowledge. Market participants who are not well informed about market prices do not have to worry about submitting an off-market price and get picked-off by better informed players. For both types of participants, coming up with a demand or supply at the displayed prices involves less burdensome strategic calculation than coming up with both prices and quantities—which are typically required in a limit order market. This goes back to the principle of simplifying bidding strategies. Remember that we are dealing with a market that has not yet developed sufficient organic liquidity.

Secondly, although prices are not required, the auction algorithm can easily incorporate price-contingent bids. For example, an insurance company that wishes to receive LIBOR and pay SOFR plus spread at the 10-year maturity could submit an instruction that says: “submit a supply of 100 million notional as long as the displayed LIBOR-SOFR spread is less than 40 bps.” In our specific numerical example, this insurance company’s order will be $0.1 billion of the $250 billion shown at the 10-year maturity. If the 10-year spread goes above 40 bps later, the $0.1

[3] Spoofing refers to the practice of submitting an order with the intention of canceling it before execution. For example, a trader may submit a large buy order to create an impression that the price will increase, and he aims to cancel the large buy order before a large sell order hits it. If supply and demand are made fully transparent, this transparency could make spoofing easier.

billion supply will be withdrawn. All this can be easily implemented by an algorithm that bids on behalf of participants.

Thirdly, one may wonder what happens if a participant has a demand or supply at a maturity not displayed on the clocks. For example, a maturity of 25 years, 1 month and 3 days is unlikely to be part of any practical maturity grid. The short answer is that the participant should submit at the closest displayed maturity, say 25 years or 25 years and 3 months. We will discuss in Step 5 how the resulting small maturity mismatch is handled through post-auction compression.

Step 3. Price adjustment and price discovery across maturities

If the total demand and the total supply at the currently displayed spreads do not match each other, the spread should adjust. **On any maturity for which the demand and the supply are sufficiently far from each other, the corresponding spread is adjusted in the direction of shrinking the imbalance and by a predetermined increment.**

Table 3.3 below illustrates this process. The demand and supply of Table 3.2 suggest that the spread should move up across all maturities. Suppose that they are moved to 20 bps in the four example maturities. (We discuss shortly who move the spreads and how the increments are determined.) Then, at these new spread, the bidding process in step 2 repeats. Presumably, fewer participants are willing to pay the higher spread and more participants are willing to receive the higher spread. The resulting supply and demand are shown in the bottom table. The imbalances are now much smaller but still nontrivial. Note that if the demand exceeds the supply, then the spread should adjust down.

Maturity	2y	5y	7y	10y
Spread (bps)	20	20	20	20
Demand ($bn notional)	75	120	150	150
Supply ($bn notional)	80	180	180	200

Table 3.3: New spreads and new demand/supply

Discussion. There are two design issues on the adjustment of the spread: how big is the spread increment and who does the adjustment?

In principle, the size of the increment should be large if the supply/demand imbalance is large and small if the supply/demand imbalance is small. A “safe” method is to pick a minimum tick size, say 1 bp, and adjusting it one tick at a time. Alternatively, the spread could be adjusted in multiple ticks in one go; if overshooting happens, it is adjusted backward.

“Who does the adjustment” is really about to what extent the spread adjustment should be left to the participants as opposed to the auctioneer. There are two choices here:

- The auctioneer adjusts the price in each round, so the only required action of the market participants is to submit the quantity of demand or supply at the current spreads. This method is standard for auctions of spectrums and electricity, for example, but not too common in financial markets.

- An exclusive set of “market makers” or “quote providers” adjust the spreads, and other market participants only submit demand and supply at the (best) quoted prices. This mechanism is close to the current exchange trading of equities and derivatives. This choice includes the “corner” scenario in which every single participant can adjust the spread.

There are several reasons to let the auctioneer, the party that runs the auction, adjust the spreads. First of all, the action of displaying the spread does not mean that the auctioneer will make transactions; only payers and receivers of the spreads of the basis swaps will be trading. The role of the auctioneer boils down to electronically “shouting out” prices and soliciting actual participants to submit demand and supply. Thus, the auctioneer need not be an expert in pricing basis swaps. The second reason for letting the auctioneer adjust the spread is for simplicity and consistency because there is only one spread displayed for each maturity. Third, the auctioneer is likely a neutral and impartial party in the underlying basis swaps. Other market participants such as dealer banks are likely to have substantial positions in IBOR derivatives. The design should minimize the perceived (or actual) risk, however small, of the quote being manipulated.

Step 4. Closing of the auction

The auction closes once the demand-supply imbalance is smaller than a pre-determined number δ on all maturities, where δ is a positive parameter close to 0. If the supply and the demand are not exactly equal on a maturity, the heavy side is rationed.

Two features here are worth emphasizing. The simpler one is that the exact matching of supply and demand is not necessary; in fact, it cannot be obtained in general because the tick size is discrete. A small parameter δ allows this flexibility. A possible constraint under this feature is that $\frac{|D-S|}{0.5(D+S)}$ is smaller than, say, $\delta = 5\%$. Rationing the excess supply or demand is a standard way of clearing the market, as in Treasury auctions. The method of rationing may be pro-rata or by time priority. Time priority seems preferable because it strengthens the incentive to submit demand and supply early.

The more substantive feature here is that no maturity closes earlier than others. For operational simplicity, it is tempting to “finish” with a maturity once the supply and the demand on that maturity are sufficiently close to each other, so that the latest displayed spread on that maturity becomes binding and final. To see the problem of this approach, suppose that the 5-year maturity is closed before the 7-year maturity. Suppose further that the demand to receive the spread jumps up substantially on the 7-year maturity afterwards. A liquidity provider may wish to respond to this new demand by increasing his supply on the 7-year maturity, but if this liquidity provider already exhausted his risk budget on the 5-year maturity, which is now closed, he simply cannot respond to this new profit opportunity. This risk reduces liquidity providers’ incentives to submit demand or supply early. A desirable feature is that, following any new supply or demand submitted on any maturity, the prices and quantities can adjust in response across all maturities; this feature is delivered if all maturities close simultaneously.

Table 3.4 below shows the spreads and the demand/supply at the close of the auction. In this example, only the 5-year maturity has excess demand, and the other three maturities have excess supply. If we pick a proportional error threshold of $\delta = 5\%$, it is easy to see that the demand/supply imbalance $\frac{|D-S|}{0.5(D+S)}$ on each maturity is less than δ. The resulting transactions have a notional amount of $77 + 158 + 169 + 178 = 582$ billion.

Maturity	2y	5y	7y	10y
Spread (bps)	25	30	32	35
Demand ($bn notional)	77	160	169	178
Supply ($bn notional)	78	158	170	180

Table 3.4: Spreads and demand/supply at the close of the auction

Step 5. Post-auction processing

After the auction, the economic exposures to IBORs are replaced, partly or entirely, by the new reference rates. The auction does not, however, automatically eliminate the operational exposure to IBORs. In fact, recall from Figure 1 that the basis swap between IBOR and the new reference rate is an overlay to the legacy trades exposed to IBOR, without affecting the terms of the legacy trades. Here is where post-auction processing would be helpful.

Derivatives. Let's start with derivatives trades, as shown in the top panel of Figure 1. If the legacy interest rate swap and the new basis swap have the same exact cash flow dates and are cleared through the same CCP, the IBOR exposures are literally netted out, leaving a "clean" interest rate swap based on the new reference rate.

This ideal scenario is likely complicated by a number of factors in practice. For example, a participant's legacy interest rate swap based on IBOR may have a maturity of, say, 10 years and 2 months, but the new basis swap established in the auction has a maturity of 10 years. If maturities are mismatched, cash flows indexed to IBORs would not cancel out exactly. In addition to creating operational inconvenience, incomplete netting may also be costly in terms of capital requirement under Basel III, if the participant is a bank or bank affiliate. The same problem shows up if the legacy IBOR swap and the new basis swap are centrally cleared at different CCPs, which again makes it difficult to net the cash flows.

Fortunately, the market already has a solution for situations like this, namely trade compression. In the example above, the legacy IBOR swap could be compressed into one with a 10-year maturity, which would then subsequently offset the new basis swap entered in the auction. Cross-CCP compression is also used in practice to deal with the cross-CCP exposures.

Note that the benefit of clearing and compression obviously rests on the assumption that such services are accessible at reasonable costs. The auctioneer running the conversion auction should therefore make sure any auction participant can access such services before auctions take place.

Cash product. If a participant's IBOR exposure is in the cash product, the two trades shown in the bottom panel of Figure 1 are more difficult to be netted or compressed into one. That is, the basis swap can be cleared through a derivative CCP but the cash product cannot. In the event that IBOR is discontinued, a player with cash market exposure to IBOR has to deal with two types of contracts, one cash and one derivative. The lack of netting between them multiplies the problem, rather than mitigating it, to which I see no easy solutions.

Given the lack of netting, it seems quite possible that households and some nonfinancial corporations may not wish to participate in the auction. Instead, their IBOR exposures in the mortgages or floating rate debt may have to be modified directly with their banks, possibly using the auction prices.

For sophisticated players that deal with cash products and derivatives on a regular basis, entering the auction to "hedge out" the IBOR exposure may nonetheless be a good idea in a mark-to-market sense. For example, mortgage banks that lend at a floating rate indexed to IBOR face large uncertainty of the market value of its mortgage portfolio if too few banks submit to the LIBOR panel after 2021. Using the basis swap between LIBOR and SOFR reduces this uncertainty in the mark-to-market value. Such players are probably equipped with the technology and access to take advantage of clearing and compression.

Voluntary conversion at auction-determined spreads. So far, we have focused on the exposures of auction participants. Now, we turn to players who, for whatever reason, do not participate in the auction but wish to use the auction-determined price. For example, nonfinancial corporations and retail customers may find it too costly to participate in auctions. Yet, their floating rate loan or floating rate mortgage contracts may be modified depending on the resulting spreads from the auctions.

Parties should feel free to use the auction-determined spreads for contract rewriting, both for derivatives and cash products. After the auctions conclude, parities can voluntarily amend their existing IBOR contracts or enter into new contracts are the auction-determined spread. Such post-auction trades have a flavor of "free-riding" on auction prices but they may be unavoidable for certain parties not equipped with trading the basis swap.

Here, the ex post and voluntary nature of side conversion serves at least three purposes. First, if parties agree to convert legacy IBOR contracts at auction-determined spreads ex post, it implies no regret, by construction. Second, because side conversion happens ex post and only if both parties agree, incentives to manipulate the conversion auction are reduced. That is, if a party pushes the spread artificially high or low, the other side can simply decline to use such prices post-auction. Third, because no side conversion is guaranteed to take place, parties that have strong desire to convert their legacy IBOR contract are better off participating in the auction, whereby contributing to price discovery instead of free-riding on it. All these properties—no regret, reduced incentive of manipulation, and stronger incentive to participate—are desirable.

2. Further Discussions

Dynamic implementation. So far, I have described the multi-maturity clock auction as a one-off event. But the auction can be implemented dynamically. For example, one could start with a narrow maturity range and gradually expands into longer maturities. This process would take advantage of already-developed liquidity in shorter maturities and speed up liquidity development at longer maturities. Likewise, the clock auction can be implemented first with the most active participants, such as large dealer banks. If early auctions are successful, then other banks, asset managers, insurance companies, pensions, and nonfinancial corporations, among others, are likely to join.

Auctions strike a good balance between a centralized, all-to-all market and bilateral markets. For instance, a daily or weekly auction that includes a currently illiquid maturity, say 5 years SOFR, requires less attention and work from market participants than listing a continuously traded futures contract. Yet, an auction that converts LIBOR to SOFR involves wider participation than a bilateral LIBOR-SOFR swap. In this sense, a dynamic implementation of auctions that gradually expands into a wider and wider maturity spectrum and more and more diverse participant types offers a good balance between coordination and flexibility.

Encouraging early bids and closing the auction on time. The feature that all maturities close simultaneously is a double-edged sword. While it facilitates arbitrage and liquidity provision across maturities, it can potentially lengthen the duration of the auction. Therefore, it is important to fine-tune rules that speed up the auction process, by encouraging participants to put in bids as early as possible. There are a number of ways to do this.

First, early bidding is encouraged by a time priority rule. That is, if rationing is needed on a maturity at auction close, orders on the heavy side are processed in the sequence of submission. Directional traders who have high urgency in shedding IBOR exposure would be incentivized to put in their orders early to avoid rationing. These early demand or supply makes it easier for arbitrageurs to judge the distribution of order imbalances across maturities and where to commit their risk capital, a virtuous circle.

The second, and perhaps more direct way of encouraging early bids is to charge a lower auction fee, or even zero fee, on early bids.

The third method of encouraging early bids is to use a version of "activity rule" that has proven effective in spectrum auctions (see Milgrom 2004). In the IBOR conversion context, an activity rule says that if the spread on a maturity goes up, no bidder can increase his demand or decrease his supply on that maturity, and conversely if the spread goes down. For instance, a participant who demands $100 million when the spread is 20 bps and later demands $200 million when the spread raises to 25 bps violates the activity rule. In this example, the activity rule encourages this specific participant to express the full $200 million demand as early as possible. Directional bidders can easily avoid triggering this rule by putting in the truthful limit orders at the very beginning. Arbitrageurs are unlikely bound by this rule because profit-maximizing arbitrageur would not demand more as price rises, or supply more as price drops. Therefore, although the activity rule may appear unfamiliar or even intrusive at first glance, it is unlikely a burdensome one. In addition, the activity rule can be implemented by the auctioneer, in the form of rejecting new orders that do not conform to it.

Commonalities and differences from Darrell Duffie's compression auction proposal. Duffie (2017, 2018) proposes to use compression algorithms for IBOR transition. The basic idea of compression is to reduce the notional amount of derivatives while maintaining approximately the same amount of economic risk for each participant. If needed, the compression algorithm can break and remake derivatives contracts. For example, a payer interest rate swap with 9-year maturity and another payer interest rate swap with 11-year maturity may be compressed into a single payer interest rate swap with 10-year maturity, if the holder of the two original swaps feels comfortable with the slight modification in the timing and the amount of cash flows.

Duffie's insight is that essentially the same compression algorithm can be applied to exchange IBOR cash flows to cash flows based on the new reference rate, by adding a spread as input from participants. For example, a participant who used to receive LIBOR will need to submit a spread threshold, so that his order to exchange receiving LIBOR to receiving SOFR plus spread is filled if and only if the market-clearing spread is sufficiently high and the resulting portfolio of derivatives is within his pre-specified tolerance. Of course, a participant can submit as many quantity-spread pairs as desired.

Table 4 below summarizes the main difference between Duffie's compression auction design and my clock auction design.

Key to both Duffie's compression auction design and my clock auction design is to harvest liquidity across maturities. These two designs differ, however, in how to achieve this objective. In the clock auction design, transparency does the job: large order imbalances are smoothed out by liquidity providers because they are displayed and easy to identify. For example, suppose that the 8-year maturity has an excess supply (of LIBOR-SOFR spread) of $10 billion and the 10-year maturity has an excess demand of $10 billion, pushing the currently displayed spread curve into a zig-zag shape. In this case, liquidity providers would submit orders in the opposite direction—more demand at the 8-year maturity and more supply at the 10-year maturity—to profit from this price "dislocation", knowing that adjacent maturities should have similar spreads by the no-arbitrage relation. In contrast, Duffie's compression auction design relies on the explicit substitution across maturities inherently in compression algorithms, up to a risk tolerance. In the above example, if participants are willing to tolerate a maturity mismatch of 1 year, then the compression algorithm would shift both the excess supply at 8-year and the excess demand at

10-year to the same 9-year maturity, matching them perfectly. Thus, the clock auction and the compression auction achieve similar objectives by different methods. This example is of course special, but the comparison applies in general.

	Duffie (2017/18) compression auction	**Zhu (2018) clock auction**
Modeled after	Compression algorithms in derivatives markets	Open/close auctions on stock exchanges; spectrum auctions
IBOR exposures	Derivatives	Derivatives + cash products
Transparency	Participants submit *sealed* bids.	Transparent; current spreads are *displayed*. Some information of supply/demand imbalance is *displayed*.
Bidding strategies	Submit {spread, side + quantity, maturity} tuples, plus price and risk tolerance.	On each maturity, at the currently displayed spread, submit side + quantity.
How are maturities determined?	Compression algorithm endogenously finds the set of maturities that satisfy the risk tolerance and maximize conversion volume (could also optimize on capital saving).	Displayed maturities are pre-determined. Transparency guides arbitrageurs and liquidity providers to maturities that have large supply-demand imbalances.
How are spreads determined?	Spreads equates supply and demand, with possible rationing.	Spreads equates supply and demand, with possible rationing.
Optimizing on capital and margin	Minimizing capital and margin requirement of the resulting derivatives portfolio could be an explicit objective of the compression algorithm.	Bidders are responsible for calculating their own capital and margin requirement, since the auctioneer does not observe their derivatives portfolios.
Dynamics	Compression algorithm is run once, after all orders are submitted.	As prices change, participants submit/revise orders, and vice versa. Auction closes once spreads on all maturities stop adjusting.
Post-auction	Contractual replacement of IBOR at auction-determined spreads	Voluntary replacement of IBOR at auction-determined spreads. Compression can be used for adjusting portfolio post-auction.

Table 4. Compression auction vs clock auction

The main advantages of the compression auction design include: (1) it builds on existing compression infrastructure, hence a "shovel-ready" project; and (2) price discovery of IBOR conversion and conventional trade compression happen together, in one algorithm, which simplifies post-auction processing.

The main advantages of the clock auction design include: (1) bidding strategies are relatively simple, especially for less sophisticated players; and (2) players with IBOR exposures in cash products can also participate, subject to the caveat that the auction probably cannot attract the least active players such as households and small corporations.

The last line in Table 4, on contractual versus voluntary replacement of IBOR at auction-determined spreads, is probably inconsequential. For example, Duffie's compression auction design may be overlaid with *voluntary* IBOR replacement post-auction, and this change would not affect the rest of his design.

3. Summary

Replacing hundreds of trillions of dollars of IBOR exposures by new reference rates is no easy task, not only for the sheer scale of the problem. The core premise that IBORs are inherently unstable due to the scarcity of underlying transactions remains valid. Regulators such as the Bank of England and the U.S. CFTC have made it clear that the transition away from IBORs will happen and the "wait and see" approach is not a constructive one. Yet, all stake holders may also worry that if the market is not "ready", a disorderly transition could risk disrupting the gigantic market linked to legacy IBORs.

I present a multi-maturity clock auction design that helps speed up the IBOR transition and helps develop liquidity in markets linked to new reference rates. In the auction, market participants who are already receiving IBOR cash flows submit orders to pay out IBOR, in exchange for new reference rate plus spread, at the desired maturity. Market participants who are already paying IBOR cash flows submit orders in the opposite direction. The key features that current spreads are displayed across maturities, and that all maturities close simultaneously, attract liquidity providers and arbitrageurs, who in turn enforce the law of one price and improve price discovery. The basis swaps produced by the auction can be subsequently compressed together with existing derivatives positions.

Extensive experience in financial markets shows that auctions can handle large transaction volumes with many participants in a short period of time. In currently illiquid markets, auctions can help develop the much needed liquidity, by virtue of coordination and flexibility. Therefore, in the context of IBOR transition, auctions should serve as a useful addition in the transition toolkit, as well as a valuable backstop in the event that organic liquidity fails to develop sufficiently fast in the marketplace.