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LIBOR Manipulation and the Transition to SOFR

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Abstract

With the London Interbank Offer Rate (LIBOR) likely to disappear at the end of 2021 due to its manipulation during the 2008 financial crisis, the financial industry must decide what to do about legacy contracts tied to LIBOR and must select a new interest rank benchmark regime going forwards. This paper provides insight into those questions by first contributing to the existing literature aimed at measuring the extent of LIBOR manipulation and then by developing a model to explain the LIBOR-SOFR spread. This paper analyzes banks' LIBOR submissions from 2006 to 2008 to identify bank collusion to strategically increase or decrease LIBOR to benefit their traders with LIBOR exposure. It then uses macro-economic data to show that LIBOR and SOFR diverge during periods of financial turmoil, and on the basis of these results makes a recommendation for how the financial industry should transition from LIBOR.

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1 Introduction

The London Interbank Offer Rate (LIBOR) has long been considered one of the most important numbers in the world. It is used as a benchmark for an estimated $350 trillion in various debt instruments and other financial products. However, in 2008 it was discovered that many major financial institutions had reported false interest rates to manipulate LIBOR to their own advantage. Britain's Financial Conduct Authority (FCA) has agreed to continue to support LIBOR only until the end of 2021. What exactly will happen after 2021 is subject to speculation. However, it is clear that the financial sector must seriously consider alternatives to LIBOR.

The impetus for this paper was to answer this question: how should we replace USD LIBOR? However, before trying to solve the immediate problem, there are a number of other questions that we might want to answer. What were the motivations behind the manipulation of LIBOR and how severe were their effects on the rate? Is it likely that LIBOR is still being manipulated? Is a transition away from LIBOR even necessary? With these questions in mind, this paper will be split into two parts. The first section contributes to the existing literature that has aimed to measure the extent of LIBOR manipulation surrounding the 2008 financial crisis. This provides insight into whether a transition is necessary at all and how LIBOR would have behaved in the absence of manipulation. This is important because many parties invested in LIBOR-based derivatives might be wary about selecting a replacement rate on the basis that it closely tracks LIBOR given that LIBOR may have been significantly different from bank's true borrowing costs during the great recession and potentially afterwards.

The second section discusses the general benefits and disadvantages associated with departing from LIBOR and analyzes whether the Federal Reserve's proposed alternative to LIBOR is adequate for individuals with LIBOR exposure. This section attempts to use macro-economic

variables to explain the differing behavior between LIBOR and the Federal Reserve's alternative, the Secured Overnight Financing Rate (SOFR).

2 The Manipulation of LIBOR

During the financial crisis, USD LIBOR was calculated by the British Bankers' Association (BBA) and published by Thompson Reuters. Each day the BBA would survey a panel of 16 major banks from all over the world, asking the question, "At what rate could you borrow funds, were you to do so by asking for and then accepting inter-bank offers in a reasonable market size just prior to 11 am?" Then, the BBA would discard the four highest and lowest responses and publish the average response from the remaining 8 banks. They would do this for each of the 15 different maturities for which USD LIBOR was calculated and publish the results at 11:30 am each day.

In 2008, LIBOR rates spiked after the Lehman Brother's Collapse and diverged significantly from the federal funds rate. This prompted investigations by the Wall Street Journal, Britain's Financial Services Authority, the US Commodity Futures Trading Commission, and other parties in the subsequent years. The submitters to LIBOR were fined over $9 Billion in total and numerous traders faced criminal charges for their roles in the manipulation of LIBOR.[1] The messages between traders uncovered by the CFTC's investigation into Barclays show just how explicit the manipulation was:

> "WE HAVE TO GET KICKED OUT OF THE FIXINGS TOMORROW!!
> We need a 4.17 fix in 1m (low fix) We need a 4.41 fix in 3m (high fix)"
> (November 22, 2005, Senior Trader in New York to Trader in London).

[1] This timeline by the New York Times references most of the major fines and criminal charges. https://www.nytimes.com/interactive/2015/04/23/business/dealbook/db-libor-timeline.html#/#time370_10983

The obvious problem with the way that LIBOR had been designed was that banks who were exposed to changes in LIBOR through their derivatives contracts would have a significant incentive to purposely misstate their survey responses with little cost to doing so. The rate is calculated as a truncated mean, which helps dampen the effects of this sort of manipulation. However, traders at LIBOR submitting banks colluded at times to get the rates they wanted.[2]

Prior to 2013, the banks' individual responses to the BBA were made publicly available, along with the overall rate itself. Perhaps this was done to increase scrutiny on banks and prevent them from misreporting. When the economy was strong, no significant problems arose. However, once the financial crisis struck, banks had an incentive to underreport their true borrowing costs (or what their true borrowing costs might have been if banks were lending to each other at all). If a bank reported a high rate to LIBOR, investors might become more fearful about that bank's ability to repay its obligations. Although this incentive for manipulation has received less public attention than the traders' explicit requests, its ultimate effect on LIBOR during the financial crisis is likely the larger of the two. All banks experienced this incentive in some form throughout the financial crisis whereas trader's incentives likely did not last as long and offset each other at times. This problem was made worse by the fact that interbank lending largely disappeared during the financial crisis, making it more difficult for regulators to determine the extent to which banks were being truthful in their LIBOR submissions.

This first half of the paper discusses the existing literature that has attempted to identify and quantify the manipulation of LIBOR. It then contributes to that literature by developing a model that attempts to explain daily changes in LIBOR submissions.

[2] Messages and testimony to support this claim were uncovered in the CFTC's investigation into Barclays.

2.1 Literature Review

The academic literature on the manipulation of LIBOR has generally been guided by goals other than the desire to provide insight for the transition away from LIBOR. For example, recently King and Lewis (2019) attempt to differentiate the impact of credit risk and liquidity on LIBOR during the financial crisis. In order to do this, they account for the motivations that led to the manipulation of LIBOR. Prior to this, Brousseau et al. (2009) demonstrated how strong statistical relationships among rates disappeared following the Lehman collapse, potentially because of manipulation (although they don't attribute it to this cause explicitly). Snider and Youle (2012) use the spread in funding costs by currency as evidence of LIBOR manipulation. Prior to the financial crisis, a common method for measuring interbank lending costs was to infer them from funds-transfers in payments-systems records, as in Furfine (1999). However, this method is no help when no transactions occur, as was often the case during the financial crisis. For this reason, even if banks submitting to LIBOR only intended to be truthful, their submissions still would've been somewhat arbitrary. With this in mind, we should reframe our goal to identify the rate that a well-intentioned banker would have submitted in response to the LIBOR survey, since there was no such thing as a bank's "true" interbank funding cost. More recent work (Poskitt and Dassanayake, 2015; Gandhi et. al., 2018; King and Lewis, 2019) has attempted to model the fundamental determinants of interbank costs to measure what LIBOR should have been without manipulation.

These authors model each borrowing bank's true funding cost as function of a time-varying market-wide liquidity premium and the bank's counterparty credit risk. Taylor and Williams (2009) use this approach immediately following the erratic behavior of LIBOR in 2008. They identify three main arguments used by traders to explain the behavior of LIBOR during that period:

counterparty risk, the liquidity premium, and future expectations. LIBOR is meant to represent an unsecured rate, and since the banks' perceived risk of default grew during the financial crisis, many authors account for this by including banks' CDS spreads as a proxy for credit risk. Traders also point to the change in the liquidity premium following the onset of the great recession. There are two main explanations for the liquidity premium. The first is that traders were reluctant to expose their bank's funds during a period where those funds might be needed. The second is that bank's needed liquidity to make their balance sheets look respectable in end-of-year financial reports. Finally, expectations regarding future interest rates became more uncertain. Towards the end of 2007, the target federal funds rate, the effective federal funds rate, and LIBOR began to diverge. Taylor and Williams as well as many following authors have used OIS spreads to adjust for expectations about future interest rates.

King and Lewis go on to attempt to capture the costs and benefits of manipulation by including the standard deviation of CDS spreads as well as the individual banks' deviations from the mean CDS spread in their model. They recognize that banks feared that by submitting a rate much higher than its peers, it might signal that it was in financial trouble. Although all of the LIBOR submitting banks shared this motivation to some extent, those banks with higher CDS spreads would have had an even greater incentive to understate their funding costs. In addition, banks may also have worried that reporting a value much different from their peers might bring unwanted regulatory scrutiny.

$$\hat{L}_{imt} = \lambda_{mt} + \phi_t C_{imt} + \beta_{1,it}\sigma^{C}_{mt} + \beta_{2,t}(C_{imt} - \bar{C}_{mt}) + \epsilon_{imt} \quad (1)$$

Equation (1) is the basic model used by King and Lewis where λ_{mt} is the liquidity premium, C_{imt} is a particular bank's credit risk (proxied by their CDS spread), and ϕ_t is the sensitivity to that credit risk.

However, this model only explicitly incorporates reputational concerns, and while reputational concerns were likely a larger factor in driving the overall LIBOR rate as discussed earlier, we should not ignore the traders' incentives for manipulation. The various investigations into the manipulating institutions by the CFTC and other government organizations have highlighted the messages between traders requesting a particular LIBOR submission for that day. However, these uncovered messages presumably only provide evidence of a small portion of the total manipulation that occurred on these grounds. Snider and Youle (2012) attempt to differentiate this type of rate-targeting manipulation by looking at how submissions bunched around pivotal quotes. Since LIBOR is calculated as a truncated mean (only the middle 8 quotes are used to calculate LIBOR), the marginal benefit of reporting a higher rate becomes 0 after a point. Snider and Youle (2012) find that submissions were bunched more tightly around these pivotal quotes than one would expect to happen in the absence of manipulation. While this provides strong evidence to suggest that banks colluded with each other – or at least were aware of what other banks would submit prior to making their own submissions – it does not tell us how large the effect of this type of manipulation was on LIBOR or how long it lasted.

Ghandi et al. (2018) attempt to show that banks' LIBOR submissions responded to their LIBOR exposure. However, because there is no publicly available information for banks' LIBOR exposure, they estimate a rolling-window regression separately for each bank-maturity pair that attempts to establish a relationship between changes in LIBOR and weekly returns for that bank. They use the coefficient associated with changes in LIBOR submissions as a proxy for a given bank's LIBOR exposure. They then use that proxy to explain monthly changes in banks' subsequent LIBOR submissions. Although they provide some evidence to support their proxy, it is still somewhat unclear whether it accurately captures a bank's LIBOR exposure. Furthermore,

evidence from prior investigations into the LIBOR-submitting banks suggests that traders did not make requests for LIBOR manipulation that lasted more than a few days. Therefore, it is not surprising that their model captures less than 3 percent of the variation in monthly LIBOR submissions. Their model, like that of Snider and Youle, provides evidence of profit-driven LIBOR manipulation, but does not give an estimate of the extent of the effect of this type of manipulation.

A majority of the papers on this subject only provide evidence that manipulation existed rather than its extent. However, most recent work has provided fairly consistent estimates of the extent of the manipulation

Table 1. Prior estimates of LIBOR manipulation

Author	**Estimate of Manipulation at peak of crisis**
Youle, 2014	-8 basis points
Poskitt and Dassanayake, 2015	-30 to -40 basis points
Bonaldi, 2017	-30 basis points
King and Lewis, 2019	-35 basis points

These results suggest that the difference between LIBOR and other interest rates during the crisis should have been even greater than it actually was although the effect of LIBOR underreporting was small relative to the size of the spread between LIBOR and other rates.

2.2 Data/Methods

Since previous researchers have already quantified manipulation on reputational grounds or have estimated the movement in LIBOR that cannot be explained by conventional determinants of interbank funding costs, the purpose of this section is to investigate the manipulation and collusion led by the banks' derivatives positions. Snider and Youle's results suggest that on days when banks colluded – particularly to increase LIBOR – the submissions around the critical quote

(where the critical quote is the fifth highest and lowest LIBOR submission for each day) are more closely bunched together. To capture this effect, we take the overall standard deviation in LIBOR submissions, the standard deviation of the eight highest submissions, and the standard deviation of the eight lowest submissions for each day at each maturity. We also attempt to control for the conventional variables that would account for changes in LIBOR submissions to the extent that the necessary data was available. In particular we use a fixed-effects model of the following form:

$$L_{imt} = \beta_1 \Delta \mathrm{FF_t} + \beta_2 \Delta C_{it} + \beta_3 \Delta \sigma_{mt}^{L} + \beta_4 \Delta \sigma_{mt}^{L8} + \beta_5 \Delta \sigma_{mt}^{L16} + \epsilon_{imt} + a_{im} \quad (2)$$

where L_{imt} is the LIBOR submission for bank i, maturity m, at time t. $\Delta \mathrm{FF_t}$ is the change in the Federal Funds Rate, ΔC_{imt} is the change in CDS spread, and $\Delta \sigma_{mt}^{L}$, $\Delta \sigma_{mt}^{L8}$, and $\Delta \sigma_{mt}^{L16}$ are the changes in the standard deviation of all LIBOR submissions, the lowest eight LIBOR submissions, and the highest eight LIBOR submissions respectively.

We obtain LIBOR submission data from 2005 until the end of 2008.[3] Without data after this point, it is difficult to say with confidence whether LIBOR manipulation continued after the financial crisis. Nonetheless, the period of 2005 to 2008 is the most interesting period for our purposes. Evidence from the investigation into Barclays suggests that the traders began manipulating LIBOR in 2005, and most of LIBOR's erratic behavior occurred towards the end of 2007 and during 2008.

CDS data was obtained via a third party from Markit, which is the same source used in most studies in this literature. Unfortunately, we were only able to get data for banks that currently submit to LIBOR rather than those that submitted during the financial crisis. We have CDS data for 10 of the 16 banks that submitted to LIBOR starting in 2006. One might fear that the banks for

[3] Thompson Reuters (the previous publisher for LIBOR data) no longer has submissions data, and the ICE Benchmark Administration Ltd. does not publish banks' LIBOR submissions, but Bloomberg has Libor submissions past 2008. Unfortunately, we did not have access to Bloomberg when collecting data for this paper.

which we have data might importantly differ from the other six banks that submitted to LIBOR at that time. For example, one might be concerned that the banks who most actively manipulated LIBOR during the financial crisis would have been eliminated from the pool of LIBOR banks. However, our sample contains many of the banks that faced the most severe punishments for LIBOR manipulation such as the Union Bank of Switzerland, the Royal Bank of Scotland, and Barclays.

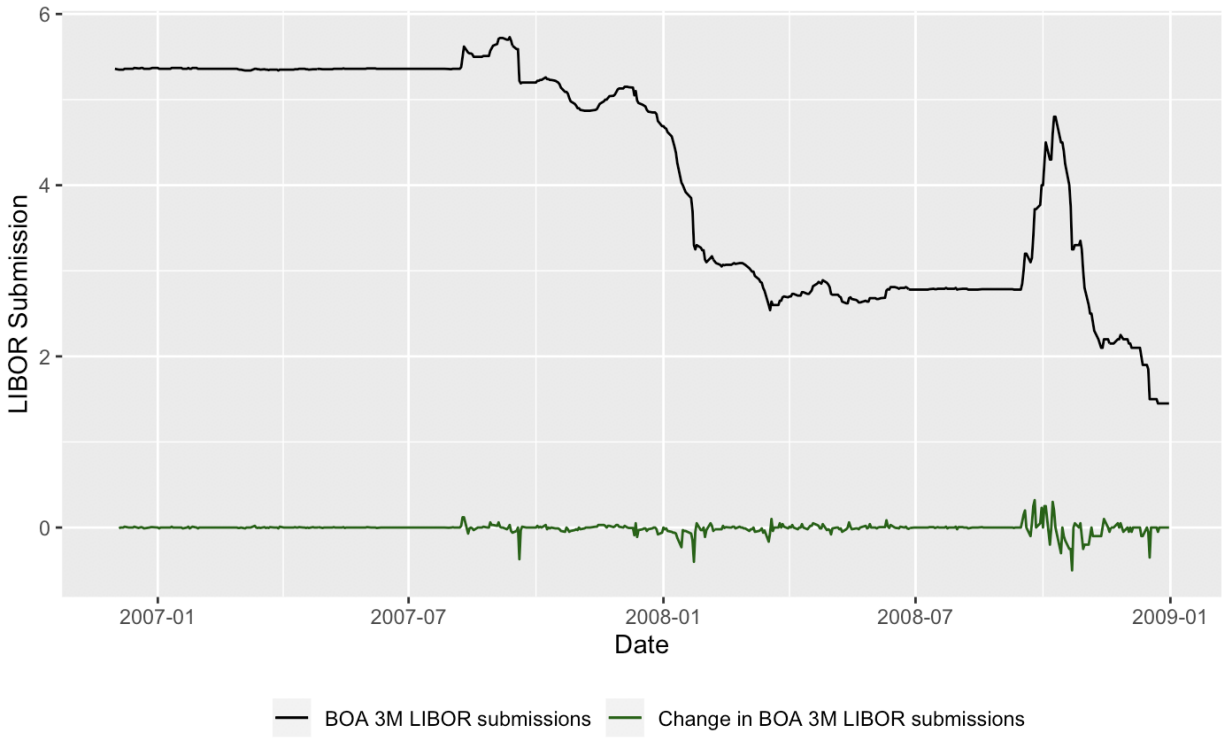
It should also be noted that Markit CDS quotes are obtained from dealers and likely contain a mix of transaction and model-based information. If the model-based quotes diverge systematically from transaction-based quotes (for example if model-based quotes are more conservative than actual transactions), then this might introduce additional uncertainty to the proxy for counterparty risk. This is an unavoidable issue faced by all users of CDS data but is nonetheless something that we should be aware of when making conclusions on the basis of this data.

Additionally, credit default swaps use different conventions for what characterizes a credit event for the purposes of the swap. The three main conventions used during this time were the XR14, CR14, and MM14. We chose to use the convention for which there is the most data available for each bank. The CDS convention used has a very slight effect on the CDS spread. However, we use a fixed effects model which transforms the data by mean differencing each variable for each bank-maturity across all T so the choice of convention would not affect the results unless it also affects the variation in CDS spreads. However, this does not appear to be the case. The difference in CDS spreads for any given bank under different conventions is relatively constant over the period.

We run an augmented dickey fuller test to confirm that both LIBOR Submissions and CDS spreads are non-stationary from 2006 to 2008 so we transform those variables by using the first

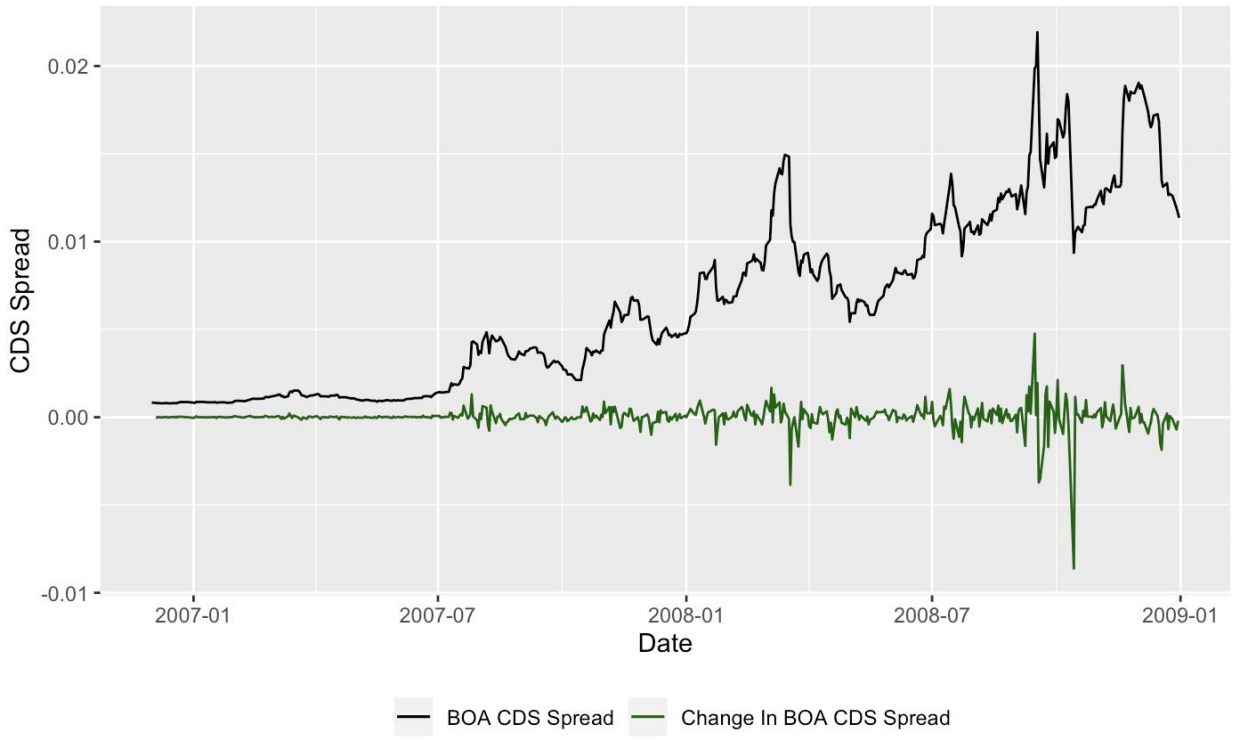
difference rather than their absolute value. Figures 1 and 2 show the CDS Spreads and 3M LIBOR submissions for Bank of America before and after transformation to avoid spurious regression problems.

Figure 1. Bank of America 3M Libor Submissions



While this graph only shows the 3M LIBOR submissions for Bank of America, they closely describe the behavior of 3M LIBOR more generally. It is important to note that the change in Bank of America's LIBOR submissions is negatively skewed. This is true across all 10 banks in the sample. One might hypothesize that this is because their CDS spreads are negatively skewed as well, but as we show, the change in CDS spreads does little to explain the daily variation in banks' LIBOR submissions. It makes sense that banks would be more willing to significantly decrease than increase their LIBOR submissions because they might worry about the reputational damage of increasing their LIBOR submission significantly relative to other banks.

Figure 2. Bank of America CDS Spreads



Unfortunately, we were unable to obtain OIS spreads for each of the LIBOR maturities. Typically, these models subtract maturity matched OIS spreads from LIBOR submissions to account for the effects of future interest rate expectations on LIBOR. While it would of course be preferable to have access to this data, there is no reason to think that the results would be biased without their inclusion.

2.3 Results/Discussion

We start by implementing a model that includes only the change in the federal funds rate and the change in CDS spreads to see whether the conventional variables explain much of the variation in the changes in LIBOR submissions. Then with later models we include variables that we hypothesized might represent the manipulative and collusive behaviors taken by the LIBOR submitters.

Table 2. Panel Data Regression Results

Variable	Model 1	Model 2	Model 3	Model 4
Adjusted R^2	0.0001	0.0045	0.3786	0.3830
Recession Indicator	---	-0.0108*** (0.0009)	-0.0110*** (0.0007)	-0.0111*** (0.0007)
Change in Fed Funds Rate	0.0277*** (0.0028)	3.4662*** (0.2214)	0.0095*** (0.0020)	0.0083*** (0.0020)
1-Day change in CDS Spread	1.9538*** (0.4778)	---	---	---
1-Week Change in CDS Spread	---	0.0261*** (0.0026)	0.4970** (0.0331)	0.4771** (0.1750)
Change in St. Dev. of all LIBOR Submissions	---	---	2.8918*** (0.0418)	0.9628*** (0.1226)
Change in St. Dev. of all LIBOR submissions*Recession Indicator	---	---	---	1.9951*** (0.1192)
Change in Standard Deviation of 8 highest LIBOR submissions	---	---	-0.7320*** (0.0331)	-0.7544*** (0.0331)
Change in St. Dev. Of 8 lowest LIBOR submissions	---	---	-0.4720*** (0.0324)	0.7525*** (0.1200)
Change in St. Dev. of 8 lowest LIBOR submissions*Recession Indicator	---	---	---	-1.2693*** (0.1197)

***p<0.001 **p<0.01

In the first model, we only include the change in the federal funds rate and the change in the banks' CDS spreads. Although both variables are statistically significant, with an adjusted R^2 of 0.0001, this model explains almost none of the variation in LIBOR submissions. It is unsurprising that the change in CDS spreads explains so little. LIBOR submitters would be unlikely to react so quickly to changes in CDS spreads, especially when there are so many other factors that might sway them every day. We then try using the change in CDS spreads over the past week, which only improves the model slightly. However, in later iterations of the model, the

1-day change in CDS spreads is not statistically significant, whereas the 1-week change is. It also just seems more reasonable to think that there would be some lag between changes in the CDS market and LIBOR submitters responding to those changes. However, if interbank lending actually had existed during the period, then the response would likely have been more immediate.

We also rerun model 2 after transforming the data into weekly data by taking the average weekly value for all of the relevant variables. This model explains 10 percent of the variation in average weekly LIBOR submission – a significant improvement over the same model on daily data. This suggests that while the changes in CDS spreads do little to explain the daily variation in LIBOR submissions, they do affect the overall level of LIBOR submissions over a longer time horizon, consistent with other methodologies that have attempted to explain LIBOR submissions using CDS spreads.

Model 3 begins to test our hypothesis regarding bank collusion. This model includes the standard deviation in LIBOR submissions of the bottom 8 submissions, the top 8 submissions, and all 16 submissions. It is important to incorporate a variable for the total variation in LIBOR submissions because it can act as a proxy for general financial conditions. When the recession worsened, some banks fared better than others, and so the variation in CDS spreads and LIBOR submissions grew (although perhaps not as much as one might expect).

The variables of particular interest are the change in the standard deviation of the 8 lowest and highest LIBOR submissions. We hypothesized that reduced variation in the 8 highest LIBOR submissions was evidence of manipulation and would therefore correspond with a higher rate on that day. Therefore, it is not surprising that the coefficient associated with this variable is negative. It is clear why LIBOR submitters would not want to report an unnecessarily high rate since it could have negative reputational effects.

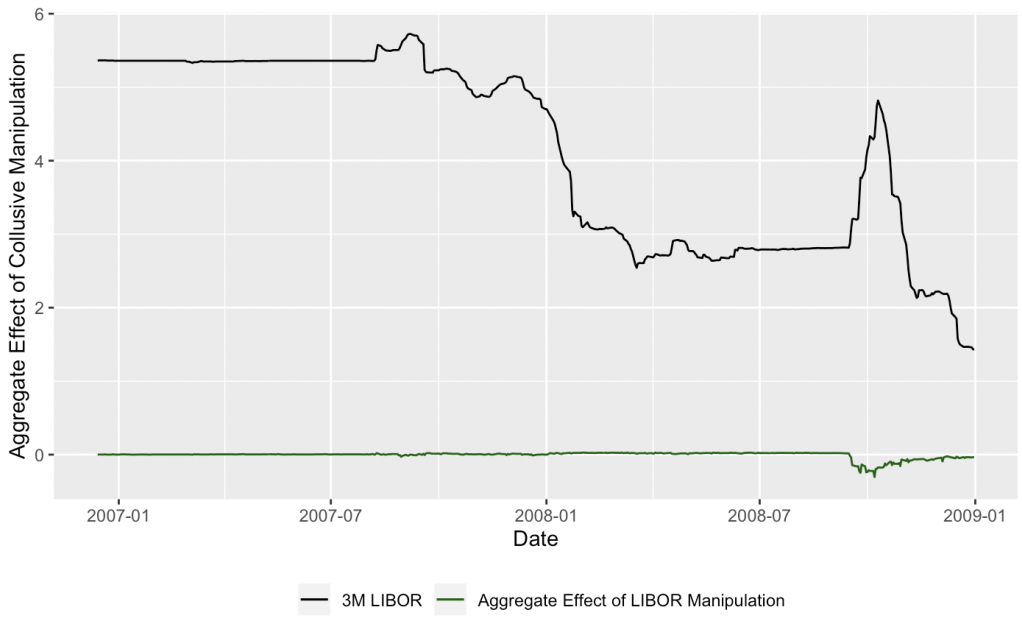
The motivations for colluding in order to get a low rate were less significant. The primary motivation, however, would be avoiding the regulatory scrutiny that a bank might draw if it submitted a drastically lower rate. For this reason, we would expect lower variation in the bottom eight LIBOR submissions to signify collusion and correspond with a lower rate. However, the results from model 3 suggest the opposite. In order to gain more insight into this, and to control for the onset of the great recession, we include a dummy variable with a value of one for every day from the beginning of December 2007 and a value of zero for all other days in the sample. By interacting this variable with the other explanatory variables, we learn a couple important things.

First, we learn that the change in the standard deviation of all LIBOR submissions had a larger relationship with LIBOR submissions during the great recession. This is not particularly surprising. If anything, it is somewhat surprising that the standard deviation of all LIBOR submissions was statistically significant at all before the great recession. More importantly, however, we learned that the relationship between changes in LIBOR submissions and the change in the standard deviation in the 8 lowest LIBOR submissions is different before and after the start of the great recession. Prior to December 2007, the data supports our original hypothesis regarding why the 8 lowest submitting banks might collude. After 2007, the relationship flips. Why might this be? Our revised hypothesis is that after the great recession hit, making an immediate profit off of LIBOR manipulation became less significant relative to the reputational damage a bank might incur by submitting a low rate.[4] Now the less financially stable banks had an incentive to move their submissions closer that of other banks. However, they still wanted to move in step with other similar banks.

[4] During the investigation into Barclays, it was discovered that the bank had changed its strategy in exactly this way in response to greater scrutiny into its LIBOR submissions during and after the financial crisis.

Originally, the purpose of analyzing manipulation caused by collusion was to determine whether it might significantly affect our estimates regarding the overall misstatement of LIBOR. However, because we take the difference in LIBOR submissions as our left-hand side variable, it is difficult to say what the aggregate effect of manipulation on these grounds was. In order to gain some insight into this question, we measure the daily change in LIBOR submissions attributable to the variables that represent potentially collusive behavior – the standard deviation in the 8 highest and lowest LIBOR submissions. Then we add the effect on day 1, to that on day 2 and so on to get an aggregate effect of collusion. Of course, this also increases the uncertainty of our estimates with each subsequent day. Nonetheless, it gives a general sense for whether the manipulation importantly contributed to the misstatement of LIBOR.

Figure 3. Aggregate Effect of Collusive Manipulation on 3M Libor



Ultimately, collusive manipulation seems to have had very little impact on three-month LIBOR. It typically only affected the rate on any given day by a few basis points. The only point

where the effect seems at all noticeable is following the Lehman Brothers collapse, but this does not seem indicative of collusion, but rather a complete lack thereof during that period of uncertainty. While traders at the LIBOR submitting banks may have made large sums via the collusive manipulation of LIBOR at the expense of other participants in the derivatives markets, the effect on the underlying assets tied to LIBOR seems to have been minimal.

3 The Transition to SOFR

Because LIBOR will potentially no longer exist after 2021, banks and investors will soon need to transition to some alternative rate. For the United States, it seems increasingly likely that the alternative will be the Secured Overnight Financing Rate (SOFR). Created in 2018 by the Federal Reserve, SOFR is calculated as a volume-weighted median of transaction level tri-party repo data. LIBOR and SOFR differ in a couple important ways. First, SOFR is transaction-based. This means that it would be far more costly to manipulate than LIBOR. Second, it is a secured rate, which might lead one to think that it would diverge from an unsecured rate like LIBOR during a recessionary period. Because the two rates have historically differed, any financial product that was originally tied to USD LIBOR will need some additional adjustment to SOFR.

This section of the paper has two main goals: to identify the most reasonable adjustment to SOFR and to discuss whether the introduction of SOFR should necessarily entail the demise of LIBOR.

3.1 Literature Review

The academic community has not yet weighed in regarding the exact adjustment to SOFR. However, some authors have made arguments regarding the proper benchmark regime going forwards. Duffie and Stein (2015) argue that one glaring problem is that LIBOR's use in bank-

related lending applications is overshadowed by trade in interest-rate derivatives tied to the same benchmark. As of 2014, an estimated $141 trillion in derivatives contracts were tied to USD LIBOR compared to only $7.4 trillion in loans.[5] This means that even if the calculation of LIBOR were changed to be transaction-based, the incentive to manipulate would persist. It is for this reason that the Federal Reserve's Alternative Reference Rates Committee (ARRC) recommended the Secured Overnight Financing Rate (SOFR) as a replacement for LIBOR. However, this is not necessarily a basis for abandoning something similar to the LIBOR benchmark altogether. Duffie and Stein argue that it is valuable to have a benchmark for hedging a bank's loan funding costs and that some formulation of LIBOR should continue exist, but that for the majority of users of interest-rate derivatives who are simply aiming to make a speculative bet on market wide interest rates there should be a secondary benchmark such as SOFR. This idea that the departure from LIBOR is an opportunity to head towards a more ideal benchmark regime is an important point. However, as the problems associated with transitioning to SOFR loom especially large, it has received little discussion elsewhere in the academic literature.

The subsequent problem for transitioning to SOFR is to decide on the adjustment that should be made to minimize the change in the value of LIBOR-based contracts. While this has been the subject of multiple consultations by the ARRC and the International Swaps and Derivatives Association (ISDA), academics have so far paid it little attention. Perhaps in an attempt to simplify the complexity of making the transition to SOFR, both the ISDA and the ARRC have been satisfied to adjust SOFR based on the median historical difference between it and LIBOR. A recent ARRC consultation argued that because LIBOR spreads are stationary and typically revert to long run values within a year that using a static adjustment is reasonable.

[5] Calculated from data from the FSB's 2014 report on interest rate benchmarks. https://www.fsb.org/wp-content/uploads/r_140722b.pdf (p 243)

However, the LIBOR-SOFR spread could potentially diverge significantly in the interim. Therefore, in this section we will attempt to provide a dynamic adjustment based on macroeconomic variables.

One alternative to using historical data to select the SOFR adjustment, proposed by Duffie (2018), is to use a conversion auction to determine a fixed compensation rate that would be given to LIBOR receivers. In a basic conversion auction, a bid consists of a pair (r, q) where r represents the compensation rate the bidder is willing to pay to convert the legacy contracts – up to the notional quantity q – to a new contract that pays the new rate (SOFR). The market clearing rate would also be applied to non-bidding market participants who had previously signed a protocol to convert their LIBOR contracts at the auction-determined compensation rate. This approach is appealing because it has the potential to circumvent some of the legal challenges that might arise when transitioning to SOFR and it avoids the need to explicitly use uncertain historical data when selecting the compensation rate. However, many of the details of such an approach are unclear. It would require the participation of numerous parties, and it could be difficult to ensure that major financial institutions don't have an incentive to manipulate the outcomes of the auctions. For these reasons, it is still worthwhile to investigate other methods for setting the adjustment to SOFR.

3.2 Data/Methods

SOFR and LIBOR have very different risk characteristics and only seem to significantly diverge during times of financial stress, so a constant adjustment seems unsatisfactory. However, running a simple model that takes into account macroeconomic variables faces two obstacles: (1) LIBOR was being manipulated during the financial crisis, and (2) SOFR did not exist during the financial crisis.

As we discuss in the first section, previous research has shown that the manipulation of LIBOR for reputational reasons was at most around 40 basis points, and collusive manipulation for immediate profit-driven motivations seems to have been even more minor. The adjustment between SOFR and LIBOR need not perfectly explain the difference between the two rates. Instead the adjustment just needs to be sufficient for investors to feel confident that it will account for the general differences in the behavior of LIBOR and SOFR during times of financial stress.

As for the second problem, although SOFR was only created in 2018, all of the necessary data to calculate the rate exists from 2014 onwards. Furthermore, the Federal Reserve Bank of New York (FRBNY) has surveyed primary dealers each morning about their borrowing activity the previous day since 1998. Based on the results of that survey, they released the volume-weighted mean rate of the primary dealers' overnight Treasury General Collateral repo borrowing activity for the past 22 years. Furthermore, the Depository Trust & Clearing Corporation (DTCC) releases their own GCF Repo Indexes that are based on a slightly different subset of transactions than those used to calculate SOFR. Since this is a subset of the actual data used to calculate SOFR, it functions as a fairly good proxy. We use the DTCC GCF Repo Data and FRBNY survey to create a proxy for SOFR going back to before the start of the financial crisis. This proxy along with actual SOFR data from 2014 onwards allows us to develop a model to explain the difference between three-month USD LIBOR and SOFR. A similar approach would need to be taken for every maturity. We focus exclusively on the three-month maturity here because it is used for a majority of the derivatives tied to LIBOR.

We obtain historical data for the S&P 500, the VIX, and seasonally adjusted housing starts over the same period to explain the behavior of the LIBOR-SOFR spread. Because housing starts data is only available on a monthly basis we calculate the average of SOFR, LIBOR, and the other

explanatory variables to produce a model using housing starts that attempts to explain the monthly LIBOR-SOFR spread in addition to a model that attempts to explain the daily spread. In particular we use a model of the following form:

$$L_t - SOFR_t = \beta_0 + \beta_1 \text{VIX}_t + \beta_2 VIX_t^2 + \beta_3 \Delta S_t + \epsilon_t \quad (3)$$

where VIX_t is the VIX spread at the start of each day, and ΔS_t is the change in the S&P 500 on the previous day. For the monthly model, we use the average value for all these variables and include seasonally adjusted housing starts as a fourth explanatory variable.[6]

3.3 Results/Discussion

We run a simple linear model that uses a combination of the FRBNY survey rate and DTCC GCF Repo Rate to estimate SOFR over the period during which the data overlap. Although the survey rate is a volume-weighted mean rate rather than the median that is used to calculate SOFR, and the DTCC GCF Repo Rate is based on a subset of the transactions used to calculate SOFR, the model explains 99.7 percent of the variance in SOFR. Given how well the proxy explains SOFR, we feel comfortable using it along with actual SOFR data to calculate the difference between SOFR and LIBOR.

[6] We also tried including the average CDS spread among the banks for which we already had data. However, because its inclusion significantly reduced the number of periods for which we had data and it did not improve the model much, we ultimately excluded this variable from the analysis. Additionally, one wouldn't want to base the LIBOR-SOFR spread adjustment on CDS data since it can be more easily manipulated than the VIX.

Figure 4. SOFR vs SOFR Proxy

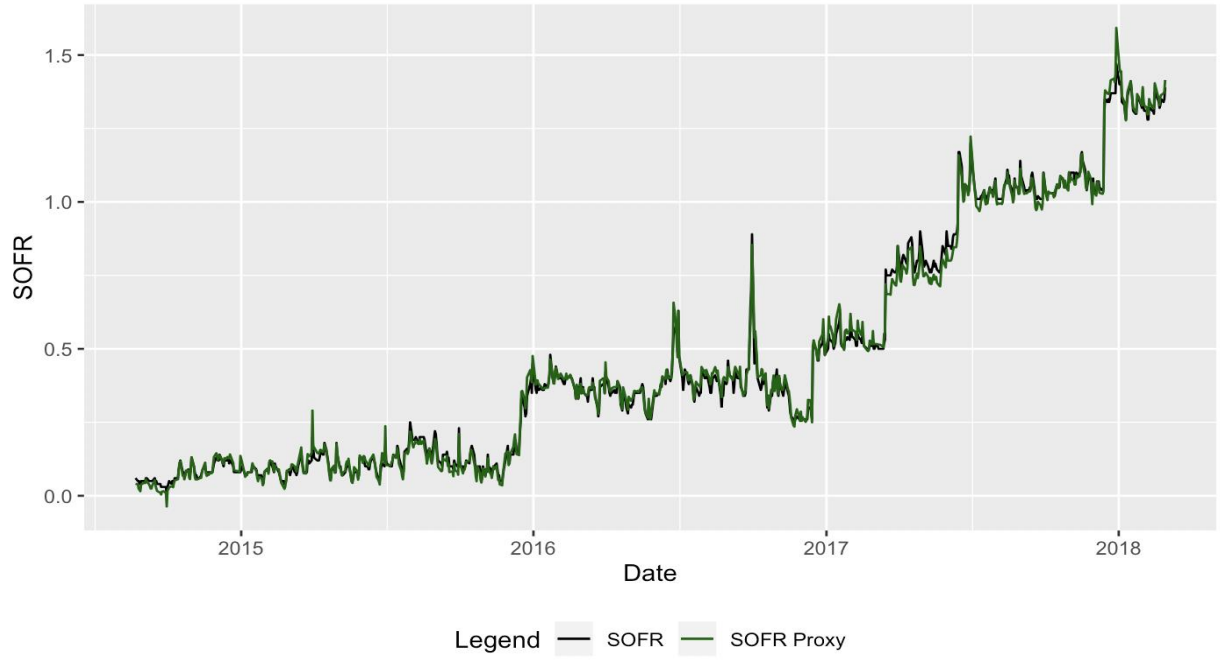
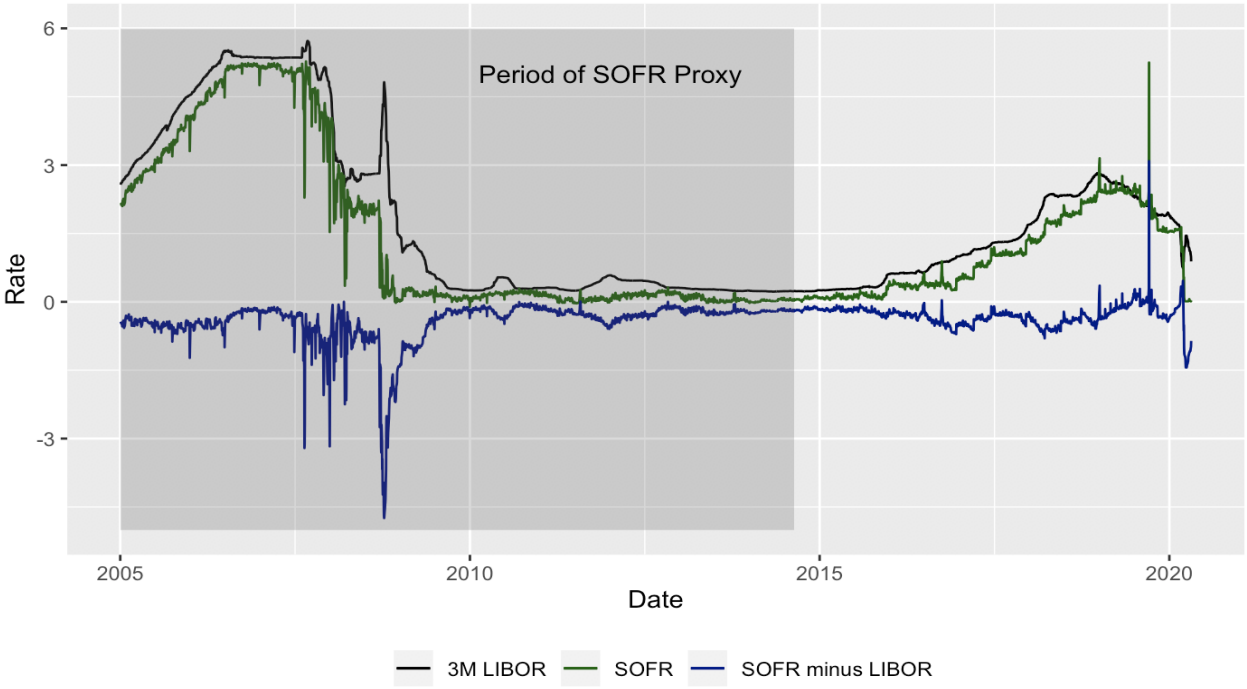


Figure 5 gives us a better sense for how much LIBOR and SOFR diverged during the financial crisis. Most of the professional discussion around the LIBOR-SOFR adjustment has focused on data from the past 5 years when the two rates rarely diverged more than 50 basis points. As the COVID-19 pandemic has created economic uncertainty again the two rates have begun to diverge.

Figure 5. SOFR vs 3M LIBOR



We first develop a model by transforming the daily data into monthly data and using a combination of VIX spreads and seasonally adjusted housing starts data to explain the difference between SOFR and LIBOR. This model explained 44 percent of the variation in the monthly SOFR-LIBOR spread. However, if we were to use this model to create an adjustment to SOFR, we would only have access to the previous month's data. Therefore, while this model supports the idea that LIBOR and SOFR diverge during times of greater volatility, it would not be useful for setting an adjustment to SOFR going forward.

Table 3. Time Series Regression Results

Variable	**Model 1 (Monthly)**	**Model 2 (Daily)**	**Model 3 (Daily)**	**Model 4 (Daily)**
Adjusted R^2	0.4294	0.3256	0.3209	0.3726
Intercept	-0.4525* (0.1937)	-0.0929*** (0.0127)	-0.0835*** (0.0126)	0.3022*** (0.0250)

Housing Starts	0.0002* (0.0001)	---	---	---
VIX Spread	0.0333*** (0.0050)	0.0258*** (0.0006)	0.0253*** (0.0006)	-0.0076*** (0.0020)
VIX Spread Squared	---	---	---	0.00053*** (0.00003)
Change in S&P 500	---	0.0014*** (0.0003)	---	---

***p<0.001 **p<0.01 *p<0.1

We then try using daily data instead of monthly data. The VIX close from the previous day explains about one-third of the daily variation in the LIBOR-SOFR spread. The VIX has a positive relationship with the LIBOR-SOFR spread. However, when we include the VIX squared variable, the coefficient associated with the VIX becomes negative. This suggests that small increases in the VIX don't have much of an effect on the LIBOR-SOFR spread, but large changes in the VIX do.

Nonetheless, much of the variation in the LIBOR-SOFR spread remains unexplained. Another potential reason that the two rates diverge in times of financial stress unrelated to the VIX or the S&P 500 comes from the fact that SOFR is transaction based. We would expect cash lenders to increase the rate at which riskier borrowers will be charged. However, in especially bad financial conditions they might choose not to lend to those market participants entirely thereby driving down the median rate paid. This is a somewhat unavoidable downside to transitioning to a transaction-based benchmark, but it suggests that a model like the one proposed here could be further improved by incorporating the change in the volume of transactions used to calculate SOFR.

Figure 6. LIBOR-SOFR Spread after adjustment

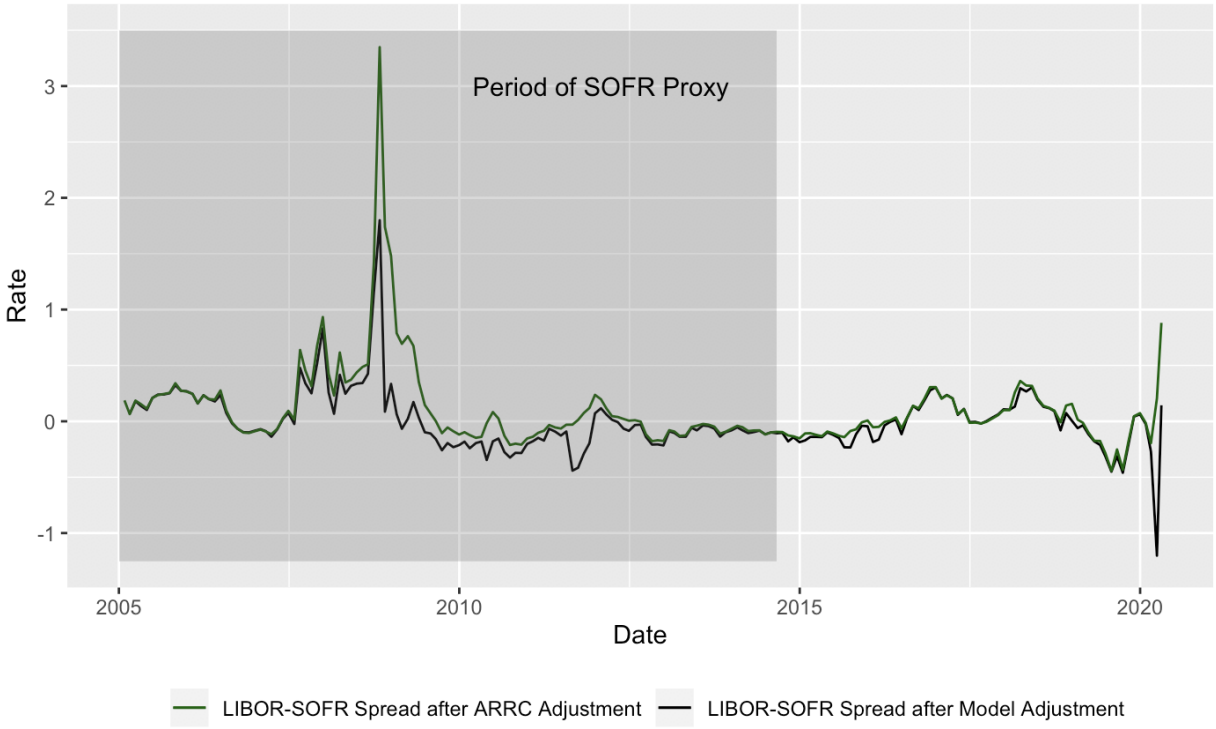


Figure 6 compares the average difference between LIBOR and SOFR each month after making an adjustment based on the above model and on the ARRC's proposal. The ARRC's proposal to add to SOFR the median difference between LIBOR and SOFR does surprisingly well. Using either adjustment, the LIBOR-SOFR spread is reduced to less than 50 basis points for almost every month. The only periods for which this is not true are the month following the collapse of Lehman Brothers in 2008 and the month following the COVID-19 outbreak. The model based on VIX spreads much better explains the LIBOR-SOFR spread in 2008. However, it over-adjusts for the corona virus pandemic whereas the ARRC's methodology under-adjusts in both cases. Given the unique nature of the current economic downturn, it does not seem particularly worrisome that the VIX-based model poorly explains the current LIBOR-SOFR spread. The VIX-based model seems superior to the ARRCs methodology, but one might argue that the simplicity of the ARRC's approach in part makes up for its reduced accuracy.

4 Conclusion

While the evidence of LIBOR manipulation necessitates some sort of change, it appears that the effects of the underreporting were less significant than one might initially fear. Prior authors have shown that reputational concerns caused banks to underreport by as much as 35 basis points. However, these reputational concerns are mostly irrelevant since LIBOR submissions are no longer made public. This paper shows that while collusive behavior motivated by the banks' own LIBOR exposures explains much of the daily variation in LIBOR submissions, the overall effect of these activities rarely surpassed a few basis points. Furthermore, with increased regulatory scrutiny and the severe fines imposed on banks as a result of their behavior, it seems likely that bank collusion has declined significantly.

Nonetheless, with LIBOR-based derivatives outweighing LIBOR-based loans nearly 20 to 1, the incentives for manipulation remain problematic. Therefore, as seems increasingly likely, all LIBOR-based financial products should transition to SOFR at the end of 2021. This paper maintains that a dynamic adjustment is preferable to the sort of static adjustment currently under consideration by the ISDA and the ARRC. However future work will likely be needed to investigate whether the LIBOR-SOFR spread can be explained by other variables – specifically the change in the volume of the transactions used to calculate SOFR. Market participants dissatisfied with the recommendation made by the ARRC could choose to participate or accept the results of conversion auctions like those suggested by Duffie (2018).

One problem with transitioning away from LIBOR is that banks would now face the risk of SOFR diverging from their cost of funds. For this reason, one might prefer that the loans tied to LIBOR and the swaps connected with those loans remain LIBOR-based after 2021. However, LIBOR is no longer a good representation of banks' cost of funds. The volume of interbank loans

has declined to less than one-fifth of what it was prior to the 2008 financial crisis, and new capital requirements continue to pressure banks away from interbank lending. Therefore, it would be ideal that a new LIBOR+ be created to for the purposes of new loans and the swaps associated with those loans. LIBOR+ wouldn't necessarily need be transaction-based so long as it accurately captured banks' cost of funding. As argued by Duffie and Stein (2015), this LIBOR+ would be based on unsecured bank borrowing from *all* wholesale sources including nonbank investors in commercial paper and large denomination certificates of deposit. This sort of two benchmark regime would be ideal. Most interest rate derivatives would be tied to SOFR, but banks would still be able to make loans at their cost of funds.

Nonetheless to smooth the process of transitioning away from LIBOR, all existing LIBOR-based financial products will need to transition to SOFR. The COVID-19 pandemic has made it all the more clear that a static adjustment to SOFR is an unsatisfactory way to compensate LIBOR-receivers. The LIBOR-SOFR spread grows during times of financial stress and therefore a dynamic adjustment like the one modeled in this paper is preferable.

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