ABSTRACT

Market Responses to LIBOR Misrepresentation of Credit Risk

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The London Inter Bank Offered Rate, or LIBOR, is used to reflect the cost of unsecured, overnight debt for large financial institutions and is used to price over $300 Trillion in financial contracts, worldwide. Although banks were penalized for defrauding the process of fixing LIBOR during the 2007-2009 Financial Crisis, no papers have studied the influence that LIBOR submissions had on other credit-risk indicators. In this paper, I use a Granger Causality Test to determine whether LIBOR submissions Granger Cause movements in these indicators. I find that changes in LIBOR rates Granger Cause changes in other credit-risk indicators but show a meaningfully different relationship from 2007-2009. The post-crisis relationship strengthens and suggests a restoration of confidence from 2010-2017. I interpret this as evidence of the isolated costs of LIBOR misrepresentation upon the functioning of broader credit markets and the restoration of market balance by market participants and regulations.

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DEDICATION

To my family and close friends: your support and encouragement has been a tremendous help through my journey.

CHAPTER ONE
LIBOR History

In January of 1986, the British Banker's Association (BBA) convened to establish a new system of tracking overnight rates for large institutions, called the London Interbank Offered Rate or LIBOR. It is used to reflect the interest on short-term, unsecured borrowing between banks and is denominated in multiple maturities across 5 currencies: The Euro, the British Pound, the US Dollar, the Japanese Yen, and the Swiss Franc. LIBOR calculations draw from a reference panel of 11-16 banks for each currency. Coverage teams at the panel banks indicate at what rate they *could* borrow and submit their findings to the BBA before 11:00 AM (Greenwich Mean Time). The formula used by the BBA is a trimmed arithmetic average where, after collating the inputs, the upper and lower quartile of rates are excluded and the remainder are averaged (Intercontinental Exchange, 2013). When the day's rates are published, traders at desks across the world have 45 minutes to access the inputs and see who made them, in a form of public accountability.

LIBOR aims to provide reliable, real-time estimates of credit quality, or their ability to repay their debts, across large banks to aid in the swaps market. Swaps allow banks to hedge interest rate exposure by paying to swap a fixed interest rate for a spread (or small markup) above a flexible rate like LIBOR. So, if rates were to drastically change relative to the fixed estimate, banks' return on lending or cost of borrowing more accurately reflect the market rate. In the event that banks do not hedge interest rate exposure, changes in real rates can mean that banks are leaving money on the table or charging far too much and discouraging potential borrowers with high rates.

Recent estimates suggest that LIBOR is used to price more than 350 trillion dollars' worth of financial instruments worldwide (Financial Services Authority, 2013). So, LIBOR's reliability is a major concern for international financial markets. In fact, the rate fixing team at the BBA was trained and equipped to publish the rate even under terror attacks, extreme weather, or any number of extreme situations.

LIBOR Scandal

LIBOR, from its inception, rapidly dominated the swaps market and had an unmarred run for the first 27 years of its use. Although LIBOR was originally posted by the British Bankers Association, it was awarded to the Intercontinental Exchange in July of 2013 after it was discovered that the rate had been manipulated by members of the reference panel. According to the Financial Services Authority, a regulatory body in the United Kingdom, banks engaged in rate-fixing throughout the financial crisis from 2007-2009. This problem occurred, in part, because the rate was not based on actual credit risk, but perceived (or stated) credit risk. Consequently, members of the reference panel acted upon the incentive incompatibility implicit in the fixing of the rates during times of financial stress (Financial Services Authority, 2013).

LIBOR rate manipulation was alleged, but never proven, until 2012 when the Financial Services Authority issued final notices to Deutsche Bank AG, UBS AG, and Barclays Bank Plc. These notices referred to the deliberate manipulation of the fixing process as an attempt to signal credit-worthiness to the market, saying:

> *Liquidity issues were a particular focus for Barclays and other banks during the financial crisis and banks' LIBOR submissions were seen by some commentators as a measure of their ability to raise funds. Barclays*

> *was identified in the media as having higher LIBOR submissions than other contributing banks at the outset of the financial crisis... The media questioned whether Barclays' submissions indicated that it had a liquidity problem. Senior management at high levels within Barclays expressed concerns over this negative publicity. Senior management's concerns in turn resulted in instructions being given by less senior managers at Barclays to reduce LIBOR submissions in order to avoid negative media comment.* (Barclays Bank, 2012)

As the FSA notice states, the actions were implemented to avoid negative attention to their higher submissions because they were suggestive of a lesser credit-worthiness (ability to repay their loans). The banks needed to appear to be less risky, so they would not signal liquidity problems and give creditors reason to doubt their ability to repay short-term, unsecured debt (Financial Services Authority, 2013). In other words, they wanted potential lenders to think they could easily repay large debts and maintain a strong network of willing lenders.

Although the structure of LIBOR-fixing permitted a degree of risk-sharing by making the process democratic, the reliance on the banks as agent to LIBOR transactions resulted in open rate manipulation, to the benefit of the bank. In many instances, communications among the bank staff show that LIBOR rate submitters colluded with traders to influence the pool of rate submissions (Chen, 2015). Such actions can be thought of as a problem of incentive incompatibility. More broadly, when an economic agent is entrusted to act in the interests of a principal and the interests of the principal and agent are not aligned, the agent has an economic incentive to act in a way that is in conflict with the

interests of the principal. In this case, the British Bankers Association (BBA) entrusted member banks to submit accurate information which would be used to compute the LIBOR rate, but individual banks could gain from misrepresentation in setting the LIBOR rate and arbitrage against the rate. However, as the reports note, the banks offered contracts which allowed debt-seeking market participants to pay a spread above LIBOR on countless derivative instruments including floating-rate mortgages and various interest rate swaps. Consequently, the bank benefitted from the hidden information about its own liquidity, but was not responsible for honoring the rate in the open market.

CHAPTER TWO
Regulatory Response

Incentive Problems

In an essay by Jiakai Chen on the LIBOR rate manipulation, he outlines numerous incentives for banks to manipulate rates and examines the magnitude of the manipulation (Chen, 2015). To him, LIBOR manipulation provided 3 distinct incentives for banks. First, rates are tied to the profitability of derivative trading positions and affecting the spot rate (the price at the moment of the rate quote) can generate short-term profits for the bank. This concept is expressed as reset risk wherein outstanding swaps are repriced at intervals throughout the year and traders can make their returns look better in the short-term with a favorable repricing. Basically, on the date that a loan payment was to be made on a LIBOR-based contract, traders would ask submitters to give low estimates so they wouldn't have to pay as much to their creditors. Second, numerous loans are quoted as a spread above LIBOR and the spot rate, again, can affect the return on these loans. This means that on interest payment dates, high LIBOR results in higher income for the banks. So, on days where high volumes of loans were to be repaid, creditors would ask for high submissions so they could get repaid more. Finally, as noted above, a low LIBOR rate signals a strong balance sheet for banks and affects the bank's reputation. His findings suggest that banks have little incentive to report their true borrowing costs, but that banks take on risk by misquoting to a large degree. Consequently, banks are inclined to quote their rates in a strategic manner and to monitor the potential submissions of their counterparties. To him, "the equilibrium strategy of banks under the current mechanism leads to an understated

LIBOR rate. Releasing banks' LIBOR submission to public also causes a signaling effect, which causes even more LIBOR bias."

These findings are consistent with the report generated by the FSA because many of the communications between rate submitters and traders involved discussion about where other banks were likely to quote their rates (Financial Services Authority, 2013). However, banks opted to periodically quote a higher rate, either to affect the day's cash flows or to 'revert to the mean' from a consistently low reporting spell. Banks understood that consistently submitting low LIBOR submissions would cause their regulators to be skeptical of their submissions. They also knew that consistently low submissions would negatively affect their profit margins. So, they often adjusted their rates positively AND negatively.

The LIBOR fixing process is not incentive compatible. A paper by Katherine Carson, titled "Institutional Corruption and Incentive Compatibility", uses LIBOR as a case study of incentives and their effect on the agents who chase them (Carson, 2014). In her view, LIBOR is incentive incompatible because "submitters can affect their earnings". She posits that, despite the challenges of doing so practically, any market rate should be based on actual transactions, rather than perceived capacity to secure certain rates. Carson's solution is to devise some mechanism whereby questionable submissions can be challenged by another panel bank and then confirmed by a bank's willingness to lend to the accused bank at that rate. This structure seems destructive, though, because it has been shown that banks are already willing to collude to defraud the rate and, in the event where they didn't collude, the harm to inter-bank relationships would erupt and cause liquidity to be a very precarious and feudal endeavor. Banking structures rely on trust and, despite banks largely

proving untrustworthy to the regulators, they must be trustworthy among one another. Instead, regulators have focused on two points of emphasis to solve the incentive problem (Powell, 2017). First, they have strongly encouraged the banks to change the traders' compensation structures to reflect customer satisfaction rather than volume. Such a strategy will discourage traders from trying to unload high volumes of contracts where they can influence the ultimate cost to the customer, so LIBOR will not see as much pressure from traders. The second suggestion is to replace or "heavily discourage" the use of LIBOR as a proxy for the risk-free rate. This suggestion has yet to materialize, but has been the subject of plenty of debate. If LIBOR is understood to be the risk free rate, the replacement cannot be collateralized or subject to the credit-worthiness of a single party. Further, the rate must always be redeemable by whatever entity pays out the claims on that return. So, replacing the rate is no easy endeavor, either.

Regulatory Mistake

The regulatory response to the fraudulent activity of the panel banks came in the form of penalties and a regulatory review of the price-fixing process. Regulatory bodies strongly encouraged the banks to re-evaluate the incentive structures on the trading floor, where most of the fraud was perpetrated (Financial Services Authority, 2013) (McInerney, 2012). Further, the British Banking Association (BBA) was removed from the LIBOR-fixing process and it was awarded, instead, to the Inter-Continental Exchange (ICE). Although the penalties seem somewhat severe, they were based on the assumption that LIBOR was the only rate that was influenced by the fixing process. However, if LIBOR was used as a proxy for the risk-free rate and was manipulated to signal credit-worthiness,

it is likely that LIBOR also had some effect on other financial instruments. The penalties exacted by regulators, in a monetary sense, must have been far less than the effect of the acts. In fact, reporting LIBOR over or under by one basis point can cause the estimated $350 Trillion worth of contracts to exchange around $35 Billion between contract holders. The Department of Justice states that only a few of the panel banks were held accountable and, of those, few paid more than $1 Billion in regulatory fines.

LIBOR's wide use as a proxy for the risk-free rate, paired with its use in trillions of dollars' worth of contracts, suggests that market participants actively track LIBOR (MacKenzie, 2008). Institutions like financial services companies, funds, regulatory bodies, and bankers all use the rate to inform their behavior in the market. So, if LIBOR attracts so large a following, volatility in LIBOR likely spread to other credit-risk indicators. Among the most widely used credit-risk indicators are the LIBOR-OIS spread, the TED spread, and the Fed Funds rate. So, changes in LIBOR likely influenced the market's perception of these credit-risk indicators. In the event that they do, the regulators who penalized the banks failed to assess the breadth of the fraud committed by the panel banks. In other words, they did not take into account the contagion present in credit-risk indicators as a result of the rate manipulation. Because credit-risk indicators are used broadly for assessing everything from corporate valuations to stock prices, understanding the influence that LIBOR manipulations had on them is extremely important. Further, understanding whether the relationship between these rates has returned to normal since the LIBOR fraud is necessary to continue to use them.

CHAPTER THREE
Empirical Model and Data

The Model

To test the relationship between LIBOR and credit-risk indicators, I collected a retrospective time-series on daily trading data from 2002-2017. Although seemingly arbitrary, the time frame covers all data from 2002 up through the Financial Crisis and beyond. I analyzed the data in whole and then re-evaluated for 3 distinct periods to see whether the coefficients differed in magnitude across the periods. The 3 periods that I isolated include an early period (2002-2006), a target period (2007-2009), and a late period (2010-2017). These delineations serve to control for various market conditions and isolate the recessionary economic period during which LIBOR was reportedly being manipulated; otherwise known as the Great Recession. The early period evaluates the relationships that existed between credit-risk indicators in a relatively de-regulated and healthy economy. The target period highlights the timeframe, outlined by the FSA, during which the panel banks were engaged in fraudulent activity. Finally, the late period will help to establish whether being penalized for wrongdoing actually had any meaningful effect on submissions' relationship with other credit-risk indicators. Certainly, the structural economy changed drastically over 15 years, so the large time frame serves to capture large economic cycles and contains both boom and bust trends. It also helps to establish a baseline from which the claims made by regulators may be tested. If the target period between 2007 and 2009 shows a meaningful deviation from the other two periods, then it would suggest that traders actually influenced the economic indicators and the rates in the market.

The Department of Justice notes that manipulation had been suspected but never proven since 1991 (McInerney, 2012). So, while there is already likely to be some deviation from the 'true' rate at which banks could borrow, the 2007-2009 rate fixing strategy was a little different than prior years'. The motivation behind the submissions was to signal health of the bank during a period where many banks were not healthy at all. For this period it is likely that the average submission was lower than what the bank could actually realize in the market. So, not only is it important to test the variation and trends in isolated time frames, it is also important to test the relationship to other indicators of credit health.

Because these rates are reported in different countries and on different exchanges, not all the rates were reported on each date over that time period. Many of these omissions occurred on the bank holidays observed by each of the exchanges, when no trading was permitted. Fortunately, the sample size was large enough that these omissions pose little threat to the accurate derivation of model coefficients. Further, the model applied to this data was not affected by the omissions.

In line with the methods recommended by Clive Granger, I implemented a Granger Causality test to determine the influence of LIBOR submissions on other credit-risk indicators. Granger's Causality test is a test of significance for groups of coefficients within a Vector Autoregressive model (VAR) (Granger, 1969). The formula is written as:

$$LIBOR_t^r = \beta_0 + \beta_1 LIBOR_{t-1} + \beta_2 LIBOR_{t-2} + \tau_1 TED_{t-1} + \tau_2 TED_{t-2} + \lambda_1 LOIS_{t-1} + \lambda_2 LOIS_{t-2} + \phi_1 FEDFUND_{t-1} + \phi_2 FEDFUND_{t-2} + \varepsilon_t$$

Where $LIBOR_t^r$ represents 3-month USD LIBOR on day t. The TED, LOIS, and FEDFUND variables represent the TED Spread, the LIBOR-OIS spread, and the Federal Funds rate at time t. The t-1 subscript denotes a one day lag and the t-2 subscript denotes a

two day lag. Because the model applied in this paper contains 4 variables (LIBOR, LIBOR-OIS, TED, and the Fed Funds rate), I tested whether past movements of LIBOR affected the present movements of the other credit-risk indicators. As a test for statistical significance, the model uses the null hypothesis that lagged changes of LIBOR do not significantly affect changes in the other credit-risk indicators.

The credit-risk indicators examined were the 3-month maturity on US Dollar denominated LIBOR, the LIBOR-OIS Spread, the 3 month TED Spread, and the Federal Funds Rate. The LIBOR-OIS Spread is considered to be an indicator for bank health and represents a swap contract on 3-month Eurodollar LIBOR and the Fed Funds Rate set by the central bank. The structure of the LIBOR-OIS contract allows banks to exchange fixed and variable interest rates (Kurt, 2018). While LIBOR is a factor in determining the LIBOR-OIS spread, the price captures the far more volatile difference in OIS swaps and the variation in Eurodollars (dollars traded on European exchanges). So, the relationship between LIBOR and the LIBOR-OIS spread is far less linear. The TED spread is an acronym for Treasury-Eurodollar rate and represents the spread, or difference, between a 3-month treasury bill and a 3-month Eurodollar LIBOR (Investopedia, 2018). It attempts to quantify credit-risk because it represents the premium on corporate borrowing relative to the supposedly riskless US government's credit. Although both rates are, in part, determined by changes in LIBOR, they meaningfully deviate from one another. A simple bivariate regression of LIBOR on the TED and LIBOR-OIS spread reveals that LIBOR describes 47.34% of the variation in the LIBOR-OIS spread and 16.67% of the variation in the TED spread. Further, LIBOR and both rates meaningfully deviate from one another over time.

Figure 1 reveals that the rates do show some level of co-movement when extreme shocks occur, but meaningfully deviate otherwise. In periods where LIBOR increases

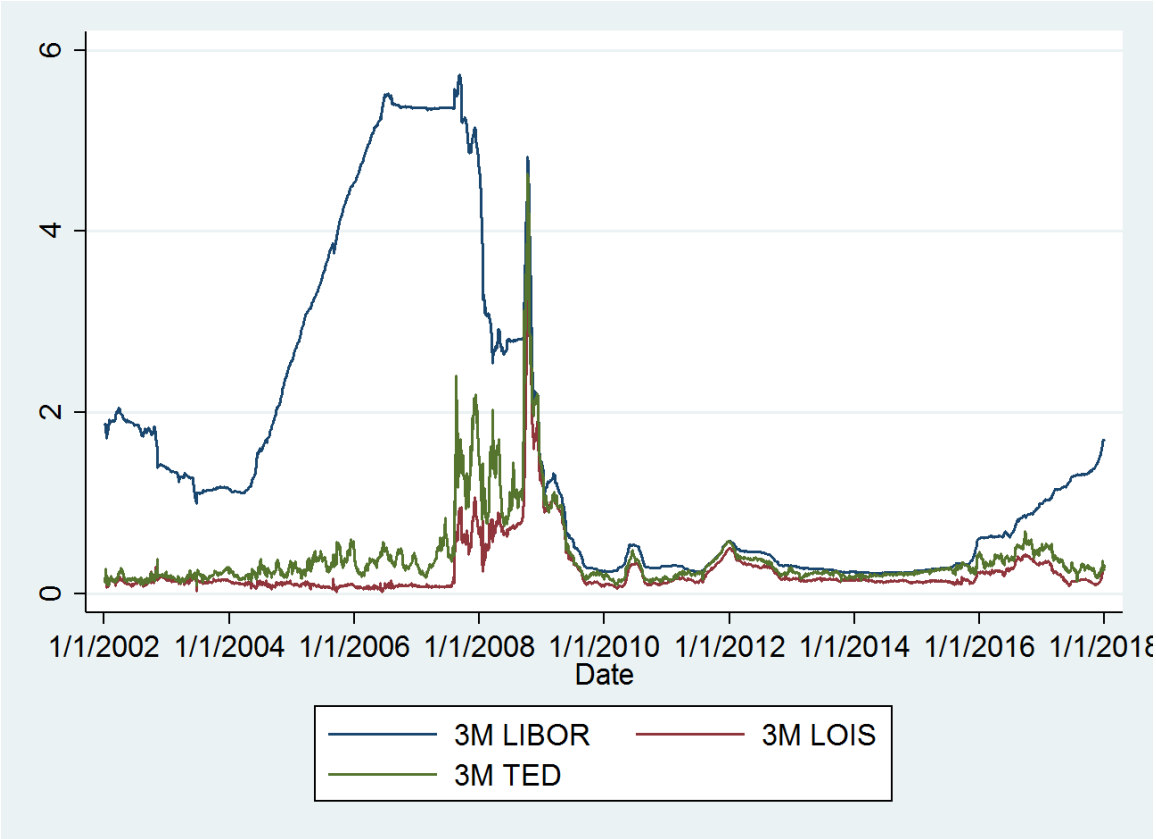

Figure 1: LIBOR and Credit Risk Indicators from 2002-2017

incrementally over time, significant volatility without strong upward trend can be seen in the LIBOR-OIS and TED spreads. So, including these variables in the model may artificially inflate the outcome, but not by much. The Federal Funds rate is also included in the model and shows how the macro-economic stability affected each of these rates. Further, studying the relationship between the Fed Funds rate and LIBOR can offer insight on how the Fed's monetary tools act in the everyday market. The Fed Funds rate is loosely targeted by the Federal Open Market Committee (FOMC), which is comprised of a panel

of senior bankers and economists (Federal Reserve Bank of New York, 2018). The rate represents the interest that member banks of the Federal Reserve charge one another for reserves. The Fed aims at the target rate by engaging in the purchase and sale of U.S. government securities, but fluctuates as banks engage in the open market. In the event that there is a strong positive relationship between LIBOR and the Fed Funds rate, the Fed is effectively tightening the money supply to restrict inflation. The mechanism is effective because it incentivizes (or discourages) banks to loan to one another, instead of deploying them into riskier assets. By adjusting the target rate, the Fed acts as a proactive counter-balance to the increasing cost of debt to the banks because increasing the Fed Funds rate means that banks don't deploy as much capital into riskier assets. So, the Fed affects interest rates and the money supply by actively managing the cost of debt.

Because every metric in the dataset except the Federal Funds Rate carries a 3 month maturity, isolating that maturity serves to reduce noise from omitted variables such as time-value-of-money differences in maturities. Another common feature of the data is that each rate is denominated in US Dollars. This allows the regression to avoid testing for differences in currencies as a part of the analysis. One weakness of the data is that LIBOR is loosely used to determine both the LIBOR-OIS swap and the TED spread. Consequently, the R-squared statistic, which shows what amount of the variation is described by the model, will be artificially high. Fortunately, the model tests for the difference in the rates rather than the level. So, when LIBOR changes, so will each of these rates, just by different magnitudes, and at different times.

Lag Selection

As a requisite component of the Granger Causality test number of lags for each variable included must be chosen. Because the data collected is observed daily but has large intraweek variance, I considered 1 and 2 days using a host of widely accepted information criterion. Both 1 day and 2 day lags show to be statistically significant, but the 2 day lag is preferred by the model selection statistics. These information criterion reward model explanatory power but penalize increasing the number of estimated parameters. The model I tested includes the 2 day specification for this reason.

The Baseline Output

This Granger Test output covers the time period 2002-2017 and represents the baseline against which isolated time periods could be compared. It shows that the daily change in LIBOR Granger Caused changes in the LIBOR-OIS spread (LOIS) and the Fed Funds Rate (FFUND). The test statistic suggests that lagged time series of LIBOR are statistically significant for explaining movements in both rates. This result is surprising because typically the Fed Funds Rate is thought to be far more "sticky" than market rates. That is, the Federal Funds Rate presumably resists changes in the broader economy and is less likely to move than other rates, as a function of the Fed's active management of the rate. However, Table 1 shows that the TED spread is the only of the rates in the model that doesn't Granger Cause movements in the Fed Funds Rate. This result is also surprising because the Fed Funds Rate is manually and democratically targeted by the Federal Open Market Committee. Moreover, the Fed Funds Rate typically hovers around the target, which goes unchanged for significant periods of time and, when it is changed, is done so in small increments over time.

Table 1: Granger Causality Significance over Baseline Period

Equation	Excluded	Chi sq	df	Prob > Chi sq
LIBOR	LOIS	211.81	2	0.000
LIBOR	TED	56.972	2	0.000
LIBOR	FFUND	1.1439	2	0.564
LIBOR	ALL	217.98	6	0.000
LOIS	LIBOR	213.24	2	0.000
LOIS	TED	72.874	2	0.000
LOIS	FFUND	23.388	2	0.000
LOIS	ALL	311.02	6	0.000
TED	LIBOR	4.223	2	0.121
TED	LOIS	1.1305	2	0.568
TED	FFUND	24.889	2	0.000
TED	ALL	34.469	6	0.000
FFUND	LIBOR	38.999	2	0.000
FFUND	LOIS	96.877	2	0.000
FFUND	TED	4.9614	2	0.084
FFUND	ALL	265.67	6	0.000

Presumably, secular trends in the Fed Funds rate tightly mimic the target set forth by the FOMC. So, the degree to which the rate deviates from the target, presumably, has minor effects on the correlation with LIBOR over the time period 2002-2017. Table 1 shows that changes in the Fed Funds Rate are highly correlated with the twice lagged change in LIBOR and both lags of the LIBOR-OIS spread. It is also correlated with the one day lag of the TED spread. Interestingly, the regression coefficients for LIBOR (2) and Fed Fund are positive, suggesting that a 1 point increase in LIBOR is correlated with a .579 point increase in the Fed Funds Rate 2 days later, with a very high level of statistical significance. So, over the period from 2002-2017, actors in the Fed Funds market charged

more for debt when LIBOR increased. Interestingly, the relationship between LIBOR over this period and the LIBOR-OIS spread is observed to be somewhat erratic, with a very high degree of statistical significance. Mathematically, these rate should increase as LIBOR increases, as inferred from the one-day lag, but reports as negatively correlated with the two-day lag. In other words, the rate displays some form of reversion to the mean in the short term. This behavior is not so unpredictable, though, because the same relationship exists between LIBOR and its own lagged time series.

Perhaps most noteworthy is the sign of the regression coefficient. A positive relationship between LIBOR and the credit-risk indicators suggests that the market was actively responding to changes in LIBOR. Where a positive relationship between Fed Funds and LIBOR is present, the changes in LIBOR are changing the way the Fed targets interest rates. Although Table 2 suggests that one-day lagged LIBOR and Fed Fund do not have a significant relationship with one another, the model shows that the second lagged-coefficient is significant. The relationship shown by the two-day lag shows that LIBOR and the Fed Funds rate are positively correlated. The positive relationship suggests that the Fed Funds market responded to changes in LIBOR.

Table 2: Granger Causality Model in Baseline Period

VARIABLES (LAG)	LIBOR	LOIS	TED	Fed Fund
LIBOR (1)	0.716***	0.607***	0.144*	0.111
	(0.0300)	(0.0419)	(0.0795)	(0.108)

LIBOR (2)	-0.155***	-0.220***	0.00540	0.579***
	(0.0319)	(0.0445)	(0.0846)	(0.115)
LOIS (1)	-0.325***	-0.204***	0.0290	-0.723***
	(0.0263)	(0.0367)	(0.0698)	(0.0948)
LOIS (2)	0.157***	0.167***	0.0665	-0.619***
	(0.0247)	(0.0345)	(0.0655)	(0.0890)
TED (1)	0.0744***	0.0988***	0.186***	-0.0917**
	(0.0121)	(0.0169)	(0.0320)	(0.0435)
TED (2)	-0.0438***	-0.0872***	-0.271***	-0.0257
	(0.0100)	(0.0140)	(0.0266)	(0.0362)
Fed Fund (1)	-0.00561	-0.0410***	-0.0122	-0.00291
	(0.00626)	(0.00874)	(0.0166)	(0.0226)
Fed Fund (2)	0.00225	0.00167	-0.0764***	-0.241***
	(0.00578)	(0.00808)	(0.0153)	(0.0208)
Observations	1,531	1,531	1,531	1,531

Note: Data sample from 2002-2017

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The Early Period

The first subsample assessed the relationship between LIBOR and the other indicators over the period 2002-2006. Relative to the baseline (i.e. 2002-2017 statistics), this early part of the time series data suggests a stronger descriptive model for LIBOR. In Table 3, every variable lag reported as statistically significant except Fed Fund (1) and TED (2). Not only does this model suggest a statistical significance for both of these rates, there was no evidence of effects upon LOIS (2). The market response to changes during this period is different from the Baseline Period.

Table 3: Granger Causality Model in Early Period

VARIABLES (LAG)	LIBOR	LOIS	TED	Fed Fund
LIBOR (1)	0.361***	0.380***	0.329***	0.785***
	(0.0546)	(0.0766)	(0.117)	(0.269)
LIBOR (2)	0.677***	0.0880	0.284*	0.815**
	(0.0731)	(0.103)	(0.157)	(0.359)
LOIS (1)	-0.632***	-0.683***	-0.510***	-0.221
	(0.0345)	(0.0484)	(0.0739)	(0.170)
LOIS (2)	-0.313***	-0.312***	-0.114	0.407*
	(0.0495)	(0.0695)	(0.106)	(0.244)
TED (1)	-0.0980***	-0.0956***	-0.226***	-0.0766
	(0.0237)	(0.0333)	(0.0508)	(0.117)
TED (2)	-0.0935***	-0.0269	-0.211***	-0.338***
	(0.0225)	(0.0316)	(0.0482)	(0.111)
Fed Fund (1)	0.0218**	0.0147	0.0110	-0.207***
	(0.00845)	(0.0119)	(0.0181)	(0.0416)
Fed Fund (2)	0.00229	0.0173	7.50e-05	-0.214***
	(0.00855)	(0.0120)	(0.0183)	(0.0420)
Observations	382	382	382	382

Note: Data sample from 2002-2006

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Because Table 3 represents the end of the 20 year macroeconomic "Great Moderation," it is useful to compare and contrast the relative regulatory framework that existed here against the subsequent "Great Recession". In this time period, LIBOR (1) Granger Caused movements in every other rate in the model. One of the ways it deviates

from Table 2 is the strength of the relationship between LIBOR and the TED spread. Where Table 2 shows that LIBOR did not Granger Cause movements in the TED spread over the entire period of the data set, in Table 3 there is a significant effect. The logic behind this finding is that LIBOR, during the 2002-2006 period, significantly impacted market behavior towards the credit risk indicators.

The output also deviates from the baseline model in that it depicts exactly the kind of relationship reminiscent of an efficient market. Table 3 shows LIBOR (1) as Granger Causing movements in LOIS, TED, and Fed Fund. The coefficients for LOIS and TED show that over time, both credit-risk indicators moved in concert with the movements in LIBOR in a much stronger relationship than the baseline model suggests, given the magnitude and significance of the coefficients. Further, the Fed Funds rate reports a positive relationship, suggesting that the Fed Funds market held a different interpretation of changes in LIBOR here than in the Baseline model. So, the fact that this deviates from Table 2 suggests that at some point, LIBOR's divergence from the other rates was so extreme as to offset the structural integrity of this time period and affects the Baseline model.

The Target Period

This regression output covers the time period 2007-2009, during which the FCA found that LIBOR had been manipulated. As expected, the coefficients and relationships over this period were markedly different from the secular trends examined in the baseline model contained in Table 3. The estimated coefficients in Table 4 show that only the first lag of change in LIBOR significantly affects changes in LOIS in contrast to estimated coefficients from the early period in Table 3 where lagged changes in LIBOR Granger

Cause movements in every other credit-risk indicator. Logically, it suggests that the manipulation of LIBOR and the structural changes during this period derailed the relationship enough to offset the entire baseline model output. Perhaps more importantly, this model shows that the twice lagged change in LIBOR affects LOIS and Fed Funds, as in the baseline model. This finding is unique among the isolated periods, suggesting that the relationships, here, were enough to offset the baseline model.

As Table 4 notes, the first lag in changes of LIBOR did not affect the Fed Funds rate. This feature is distinct among all the time periods, but not the baseline model. Perhaps the Fed Funds market was ignoring signals in LIBOR over the 1 day period. This result seems compelling because the Fed Funds market, here, would be perceiving LIBOR changes as noise to some true price and the market is not being tricked. Further, the involvement of manipulation in this period would suggest that participants in the Fed Funds market are aggressively well informed. This finding is important because the participants in the Fed Funds market are the member banks, many of which serve on the LIBOR submission panels. So, banks signaled their manipulation by behaving differently in the Fed Funds market in this period, relative to other time-periods.

Yet another deviation from the other 2 isolated time periods are the coefficients on LIBOR (2) with LOIS and LIBOR. Both coefficients suggest a negative relationship, which could be explained by noting the extreme volatility noted in Table 1. Because these relationships maintain in the baseline model, it represents another example of the relationship here offsetting the other two time-periods, despite the relative number of observations (days) being far smaller.

Table 4: Granger Causality Model in Target Period

VARIABLES (LAG)	LIBOR	LOIS	TED	Fed Fund
LIBOR (1)	0.649***	0.461***	-0.124	0.186
	(0.0711)	(0.0975)	(0.200)	(0.239)
LIBOR (2)	-0.232***	-0.245***	0.0233	0.591***
	(0.0670)	(0.0919)	(0.188)	(0.225)
LOIS (1)	-0.210***	-0.000793	0.361*	-0.816***
	(0.0678)	(0.0930)	(0.191)	(0.228)
LOIS (2)	0.199***	0.182**	0.0515	-0.659***
	(0.0545)	(0.0748)	(0.153)	(0.183)
TED (1)	0.0849***	0.0975***	0.182**	-0.119
	(0.0274)	(0.0376)	(0.0770)	(0.0921)
TED (2)	-0.0586***	-0.122***	-0.332***	0.0146
	(0.0219)	(0.0300)	(0.0615)	(0.0736)
Fed Fund (1)	-0.00181	-0.0469**	-0.000648	0.0584
	(0.0151)	(0.0208)	(0.0425)	(0.0509)
Fed Fund (2)	0.0108	-0.000664	-0.0994***	-0.254***
	(0.0131)	(0.0180)	(0.0369)	(0.0441)
Observations	287	287	287	287

Note: Data sample from 2007-2009

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The sharp differences in coefficient magnitudes and significance levels between Table 3 and Table 4 is evidence of a changing relationship between LIBOR and other credit-risk indicators in the time period when misrepresentation in LIBOR was at its greatest. Because the regulatory bodies indicted the panel banks for their effect in the target

period, the rate manipulation must have had a drastic effect on market interpretation of these rates. So, compelling differences between market interpretation of LIBOR changed over the Target Period.

The Late Period

This output represents the time period 2010-2017, after the economy began to recover from the Great Recession. Over this time period, the first lag of changes in LIBOR significantly affected LOIS, TED, and Fed Fund. Table 5 is reminiscent of Table 3 because the LIBOR (1) relationships are more similar than they are with Table 5. An interesting feature from Table 5 is the positive relationship between Fed Fund and LIBOR. The coefficients for this relationship are stronger than those in Table 4, suggesting the market's confidence in LIBOR as an indicator of credit-risk was restored. This feature can be explained in multiple ways. The Fed Funds rate changed from a target rate to a target range in late 2008, so, perhaps the loosening of the rate contributed to variation that changed the relationship. Also, the Fed opted to keep rates at record low levels over that time period, so, perhaps that changed the relationship. Finally, the LIBOR price-fixing process received intense scrutiny and a decline in interest, so, perhaps that changed the relationship. Whatever the case, market responses to LIBOR over the Target Period did not continue into the Late Period. In fact, Table 5 implies the opposite: the relationship that existed before the manipulation was recovered and even strengthened.

Table 5: Granger Causality Model in Late Period

VARIABLES (LAG)	LIBOR	LOIS	TED	Fed Fund
LIBOR (1)	0.635***	0.524***	0.595***	0.795***
	(0.0418)	(0.0842)	(0.133)	(0.302)
LIBOR (2)	0.182***	0.0412	0.0559	0.633*
	(0.0489)	(0.0987)	(0.156)	(0.353)
LOIS (1)	-0.251***	-0.361***	-0.221***	-0.245
	(0.0209)	(0.0422)	(0.0668)	(0.151)
LOIS (2)	0.0614**	0.0269	0.161**	0.134
	(0.0247)	(0.0499)	(0.0789)	(0.178)
TED (1)	0.00838	0.0732***	0.158***	0.0577
	(0.0106)	(0.0213)	(0.0337)	(0.0763)
TED (2)	-0.0177*	0.0191	-0.0884***	-0.139**
	(0.00912)	(0.0184)	(0.0291)	(0.0658)
Fed Fund (1)	-0.00701	0.00318	0.00134	-0.216***
	(0.00553)	(0.0111)	(0.0176)	(0.0399)
Fed Fund (2)	-0.00901	0.0288	-0.0217	-0.0896
	(0.00908)	(0.0183)	(0.0290)	(0.0656)
Observations	766	766	766	766

Note: Data sample from 2010-2017

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The differences between the 3 subsets show an important feature about market participants' relationship with LIBOR. In Table 4, the market appears to trust LIBOR as a metric depicting the credit risk at the banks. Interestingly, the LOIS-LIBOR relationship over the 1 day lag is positive and over the 2 day lag is not statistically significant. The magnitude and significance of the relationships suggest that markets quickly adjusted for

changes in LIBOR. However, Table 4 tells of a weakening relationship between LIBOR and credit-risk indicators. The market had a delayed and mixed reaction to the changes in LIBOR, emphasized by the second lag reported relationship. Not only did the magnitude of the coefficients change, but the sign of the relationships changed as well. These relationships recovered and strengthened in Table 6, suggesting that the market restored confidence in LIBOR and strengthened their response to LIBOR relative to the early period. So, whatever relationship was present in 2007-2009, was contained to that period.

CHAPTER FOUR

Replacement Options

It is the future of the reference rate that many regulators and traders alike are discussing at length. The requisite components of a new rate are subject to a wide debate, but the most prevalent sides to the argument are those for *revising* LIBOR and those for *replacing* LIBOR Revisionists, argue that the pervasiveness of the rate in derivatives markets makes it an administrative nightmare to replace outright. They find that compelling legal entities to revisit and redesign their contracts to reflect a new rate would expose market participants to manipulation from large institutions. Instead, like Phillip Stafford in the Financial Times recommends, the rate should be "based on frequent transactions that [do] not require a component that assesses bank creditworthiness" and revised to that aim (Stafford, 2018). This view implies, correctly, that a large component of the poor incentive structuring came from LIBOR's use as descriptive statistic on bank creditworthiness. By eliminating this component of the rate, in his mind, there is no longer temptation to influence it for short-term gain. The Federal Reserve, however, seems committed to replacing the rate, going so far as to establish the Alternative Reference Rates Committee (ARRC) to refer another proxy for the risk-free rate (Bowman, 2018). One suggestion is to replace LIBOR with the Treasury repo rate which is "derived from short-term loans known as repurchase agreements, backed by Treasury securities as collateral". This rate is favorable because it is based on transactions that far exceed the market volume of LIBOR, is not based on submissions, and is publicly accessible. This rate, although not unsecured, appears to serve as the best alternative in the dialogue, to date. Another popular replacement rate is called the Secured Overnight Financing Rate (SOFR). SOFR is based

on trades placed in various clearing houses, which satisfies the need for actual transactions being used to determine the new rate (Intercontinental Exchange, 2013). The trades are based loosely on the repo funding for US Treasuries, so it's not an exact proxy for the risk-free rate. Unfortunately, international banks may find that transaction costs and currency exposure preclude them from benefitting from this alternative because it is priced in US Dollars and is secured by an American federal institution. For the global financial sphere, it is likely that each currency which endeavors to replicate this approach will have to mimic the structure of the US banking system to accomplish similar results. Alternatively, the rates they capture in their own currencies would be exposed to currency fluctuations with the US Dollar.

Interestingly, there are small exchange networks maintained by regional banks in the US which operate similarly to over-the-counter derivatives exchanges which might be a good alternative to the rate-fixing method employed for LIBOR. To enter these exchanges, a bank goes through a very invasive due diligence process which enables member banks to understand the controls and credit risk that a certain bank may hold. Once a bank is admitted to the exchange, they are subject to ongoing monitoring to ensure their standing in the exchange. Transactions in the exchange take place when a bank with extra liquidity enters the terms at which they are willing to lend and the size of the loan into competition and, if any other member bank needs liquidity, they may accept the offer. Perhaps the panel banks should engage in a similar system where banks of a certain risk profile, size, and region may enter a closed exchange network where liquidity can be traded in a similar fashion. When the market closes, the rates that are offered and then accepted can be collated, trimmed of the upper and lower quartile, and averaged to produce a new

LIBOR of sorts. This way, the rate would be based on transactions, would be more emblematic of the actual liquidity cost of the participating banks, and would charge banks for collusion.

There are multiple objections to such a structure that are worth being considered. The only way such a system would work is if the members of the exchange were bound to accept overnight unsecured lending *exclusively* from the network of participants. Consequently, some governing body would be forced to regulate and maintain this exchange. Further, rates would likely be skewed upwards because the banks would be making open offers to banks with similar characteristics and those with cash surplus would have ample demand from banks who would compete for the limited offers. Another potential problem from operating with such a system would be that to place banks into markets with similarly sized institutions would reinforce a hierarchy of banks; especially when strata are developed on size and risk profiles. This would likely discourage competition and cause the smaller banks to pay more for capital.

CHAPTER FIVE

Conclusion

No system can completely discourage risky behavior in a field based on being compensated for risk. However, submitters should not be allowed to directly affect their earnings. LIBOR, whether it gets repealed or replaced, needs to undergo changes to restore balance to the derivatives market and to be a reliable descriptor of bank creditworthiness. A lot of thought has been given to how to better structure the rate, but 2 things must happen to ensure a reliable replacement: the rate should be based on actualized transactions and it should not exacerbate information asymmetry between market participants. A closed network exchange could possibly provide a more reliable rate but would require a lot of fine-tuning to ensure it avoids minimizing market competition. A Treasury repo rate would also be a good alternative, if it can be replicated for multiple currencies. A lot of challenges must be met to transition the global financial markets away from LIBOR, but the rate's failure demands eminent changes. Going forward, regulators need to pay more attention to incentive compatibility than interest rate flexibility to ensure that financial markets are competitive for all who choose to transact in them.

The model applied to LIBOR and the credit-risk indicators showed that there was a strong effect from the panel banks' manipulation. The banks fundamentally changed the relationship between LIBOR and the market between 2007 and 2009. As a consequence, LIBOR changes affected the market's relationship with the rate. The Granger Causality test revealed the drastic effects of the rate manipulation, but also showed that structural changes that existed over the time period. LIBOR resumed its relationship post-crisis and

isolated the change to the Target Period. Banks should have been penalized far more than they were, given the changed relationship present in the target period. However, the regulatory and market responses reaffirm the efficiency of the market and restoration of confidence.

BIBLIOGRAPHY

Barclays Bank. (2012). *Final Notices - Barclays June 2012.* London: Financial Conduct Authority. Retrieved April 22, 2018, from https://www.fca.org.uk/publication/final-notices/barclays-jun12.pdf.

Bowman, D. (2018). *Second Report of the AARC.* New York: The New York Federal Reserve Bank. Retrieved April 22, 2018, from https://www.newyorkfed.org/medialibrary/Microsites/arrc/files/2018/ARRC-second-report-press-release.pdf

Carson, K. S. (2014). *Reducing Toleration of Institutional Corruption.* Cambridge, MA: Harvard University. Retrieved April 24, 2018, from https://ethics.harvard.edu/katherine-silz-carson-%C2%A0%E2%80%94%C2%A0-reducing-toleration-institutional-corruption

Chen, J. (2015). Essays in Financial Intermediation. *University of California, Berkeley*. Retrieved April 22, 2018

Federal Reserve Bank of New York. (2018, November 4). *Additional Information about the Effective Federal Funds Rate and Overnight Bank Funding Rate*. Retrieved from Federal Reserve Bank of New York: https://www.newyorkfed.org/markets/obfrinfo

Financial Services Authority. (2013). *Internal audit report: a review of the extent of awareness within the FSA of inappropriate LIBOR submissions.* London: Financial Services Authority. Retrieved March 2018, from www.fsa.gov.uk/

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica: Journal of the Econometric Society*, 424-438.

Intercontinental Exchange. (2013). *ICE LIBOR.* London: Intercontinental Exchange. Retrieved April 23, 2018, from https://www.theice.com/iba/libor

Investopedia. (2018). *Ted Spread*. Retrieved from Investopedia: https://www.investopedia.com/terms/t/tedspread.asp

Kurt, D. (2018, February 21). *What is the OIS LIBOR spread, and what is it for?* Retrieved from Investopedia: https://www.investopedia.com/articles/active-trading/061114/what-ois-libor-spread-and-what-it.aspm. (n.d.).

MacKenzie, D. (2008). What's in a number? The importance of LIBOR. *Real-World Economics Review*(47), 237-242. Retrieved September 23, 2018

McInerney, D. (2012). *Barclays Bank PLC Admits Misconduct Related to Submissions for the London Interbank Offered Rate and the Euro Interbank Offered Rate and Agrees to Pay $160 Million Penalty.* Office of Public Affairs - Criminal Division. New York City: United

States Department of Justice. Retrieved from https://www.justice.gov/iso/opa/resources/931201271017342636594 1.pdf

Powell, J. a. (2017, August 3). *How to Fix Libor Pains; The Time Has Come to Phase in an Alternative to the Interest-Rate Benchmark.* Retrieved from Wall Street Journal (Online).

Stafford, P. (2018, March 6). Replacing Libor Proves a Tough Task after Scandal: Tail Risk [Usa Region]. *Financial Time*, p. 21.