THE U.S. ADJUSTABLE RATE PASS-THROUGH BEFORE AND AFTER THE 2008 SUBPRIME MORTGAGES CRISIS

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ABSTRACT

The rates of adjustable-rate mortgages move with short-term interest rates. Since the 2008 subprime mortgage crisis, the U.S. and most international economies have been operating in the Zero Lower Bound interest rate environments, motivating this investigation into how U.S. commercial banks passed changes in their costs of funds due to changes in the federal funds rate to their adjustable rate mortgage borrowers before and after the subprime crisis. The empirical results strongly suggest that the U.S. subprime mortgage crisis of 2008 and ensuing expansionary monetary policy changed the pricing of the adjustable rate mortgages by lending institutions. **JEL Classification:** D12, D14, G2, G21, G23

INTRODUCTION

The largest component of American wealth is residential real estates. Historically, the United States has promoted home ownership through regulations and the institutional arrangements by facilitating funds from economic units with surplus of funds to the home mortgage markets. Regulation Q and the creations of the Federal Home Loan Bank Systems, Ginnie Mae, Fannie Mae, and Freddie Mac are examples of this policy. These entities made mortgage funds available to consumers at affordable rates. Consequently, in 2009, over sixty-seven percent (67.4%) of American families own their own homes.

A critical facilitator of investment in the housing market and economic growth is financial intermediation (Schumpeter, 1912; Patrick, 1966; McKinnon, 1973). Commercial banks are an integral part of the monetary policy transmission mechanism. This is due to the use of the interest rate pass-through by commercial banks to change lending rates in the economy, which in turn transmit countercyclical monetary policy measures to consumption and investment activities.

The U.S. mortgage market has experienced phenomenal changes over the last 50 years. Among many other changes, it has gone through a series of drastic deregulations in the early 1980s precipitated by the well-known savings and loan crisis, and a financial disaster of international magnitude in the late 2000s known as the U.S. subprime mortgage crisis. Since the early 1970s, the U.S. economy had experienced the oil embargo by OPEC, the financial burden of the Vietnam War, and more importantly the countercyclical monetary policy targeting levels of market interest rates. This policy resulted in extremely high inflation and nominal interest rates in the early 1980s. These factors coupled with the modus operandi of U.S. lending institutions since the 1930s (borrowing short and lending long in thirty-year level-payment fixed-rate mortgages) led to a major banking crisis in the 1980s. This crisis resulted in bankruptcies of a significant number of commercial banks and more than a half of savings and loan associations. This phenomenon is known as the savings and loans crisis of the 1980s. Adjustable-rate mortgages (ARMs) were introduced as the remedy for borrowing short and lending long because ARMs allow lending institutions to match the maturities of their financial assets and liabilities (i.e., to follow the "borrowing short and lending short" modus operandi).

Moench et al. (2010) argued that thirty-year level-payment fixed-rate mortgages and amortizing ARMs are the two most common forms of home financing options in the United States. Rates on ARMs are often determined at market interest rate. These hybrid loans usually offer a fixed rate for two to five years then switch to an adjusted rate. The thirty-year level-payment fixed-rate mortgage may be prepaid on demand. The authors posited that given the importance of residential mortgages to households and banks' balance sheets and the short-term nature of the rates on ARMs, what drives the ARM share are important to the transmission of monetary policy and should be of special interest for policymakers. As of the end of the first quarter of 2010, U.S. households owed a total of $10.2 trillion in residential mortgage debt, representing 73 percent of total household liabilities. Moench et al. (2010) further pointed out that the ARM share has reached highs of 60 to 70 percent in 1994 but declined in recent years. The authors attributed this result to the term structure of interest rates and its effects on the relative price of different types of mortgages. Evidently, the ARM share of total mortgages has increased since 2009 (Moench et al., 2010), which is consistent with changes in the term structure of the U.S. interests.

Traditionally, borrowers with excellent credit histories are considered as low-risk in lending and continued to constitute the majority of mortgage approvals. However, between the late 1900s until 2007 lending institutions approved mortgage loans for those who have poor credit history and low ability to repay and charged them higher rates. These are known as subprime mortgages. This rise of the subprime mortgage had a positive effect on the secondary market. At the peak of this boom, subprime mortgages constituted about 20% of the mortgage market. The market expanded from $65 billion in 1995 to $332 billion in 2003 (Chomsisengphet and Pennington-Cross, 2006). Affordability-based mortgages, such as interest-only loans, also grew in popularity during this time and quickly declined after 2007 (Joint Center for Housing Studies, 2008). Due to predatory lending, resetting of ARMs, and borrower overextension the secondary market collapsed.

However, McAndrews (2015) articulated at the Mortgage Contract Design, Implications for Households, Monetary Policy, and Financial Stability Conference, organized by the Federal Reserve Bank of New York, that a higher share of ARMs at the beginning of the financial crisis would have enhanced the effectiveness of monetary easing by reducing foreclosures and stimulated the macro economy. He also argued that a high share of adjustable mortgage would also result in a stronger monetary policy. This will in turn both in simplify and narrow the economic cycle.

As a result, the amplitude of interest rate adjustments by the central bank may not need to be quite as large to have the same economic effect. This may be a particularly important consideration when the economy is at, or close to, the Zero Lower Bound on interest rates, as the American and many other economies are today.

In addition, Kim et al. (2018) pointed out that nonbanks originated about half of all mortgages in 2016, and 75 percent of the mortgages insured by the FHA and the VA, which are much higher than those observed at any point in the 2000s are. The authors argued that these nonbank mortgage companies are vulnerable to liquidity pressures in both their loan origination and servicing activities and showed that the same liquidity issues unfolded during the financial crisis, leading to the failure of many nonbank companies, requests for government assistance, and harm to consumers.

Additionally, even though the targeted federal funds rate is short-term and only targeted (not an instrument), it is one of the important short-term intermediate targets of the Federal Reserve System's countercyclical monetary policy. Moreover, understanding how the pass-through from the federal funds rate to the adjustable mortgage rates vary in different interest rate environments is of substantial interest to policymakers. Since the 2008 subprime mortgage crisis, the U.S. and most international economies have been operating in the Zero Lower Bound or Zero Nominal Lower Bound interest rate environments. Zero Lower Bound is a macroeconomic problem that occurs when the short-term nominal interest rate is at or near zero, causing a liquidity trap and limiting the capacity that the central bank has to stimulate economic growth. *Therefore, the focus of this paper is to investigate how U.S. commercial banks passed changes in their costs of funds due to changes in the federal funds rate to their adjustable rate mortgage borrowers before and after the subprime mortgage crisis.* In the remainder of this paper, we first provide a summary of the U.S. mortgage sector. Then, we describe the methodology used followed by the data and its descriptive statistics. Next, we specify the model for the investigation, report the empirical results, and discuss these results. Finally, we provide observations and remarks.

THE U.S. MORTGAGE MARKET

Before exploring the relationship between adjustable mortgage rates and federal funds rates, it is useful to consider several salient characteristics of the U.S. mortgage market.

Deregulation and Securitization

Historically, the US banking regulations provided a stable and problematic environment for growth. Financing for home loans was provided primarily through savings accounts, and low-cost deposits directed toward the thrift industry. Many forms of regulation were developed such as Regulation Q, which restricted check deposits interest and placed a cap of all other rates. This caused many issues for regulators because mortgages depended on savings deposits forcing them to have long-term assets with short-term obligations (Modigliani and Lessard, 1975).

Nonetheless, Regulation Q and its associated regulations, such as usury ceilings, interest-rate caps, and limits on branching, created minimal difficulties for most of the

1940's and 1950's. However, in the 1960s inflation and interest rate caused banking cost to rise resulting in Congressional actions that reduced the mortgage market's dependence on deposits and increased the influence of capital market financing. In 1968, Congress repurposed the Federal National Mortgage Association (FNMA, founded in 1938 and now known as Fannie Mae) by dividing it into a new branch called the GNMA (Government National Mortgage Association, later known as Ginnie Mae) and retaining the FNMA as the second branch. The GNMA purchased and processed mortgages guaranteed by the VA and the FHA, while the FNMA bought other mortgages. In 1970, the Federal Home Loan Mortgage Corporation (later known as Freddie Mac) was added its purpose was to buy loans from its members.

The US secondary markets developed slowly until the mortgage-backed security began to transform the mortgage market in the early 1970s. Mortgage-backed security, with government-backed securitization trusts began to rapidly increase. Uncertainty in the thrift market and high interest rates provoked regulatory changes that included the Depository Institutions Deregulation and Monetary Control Act of 1980, which phrased out Regulation Q. Changes were also made to the accounting rules by the FHLBB (*established by the Federal Home Loan Bank Act, Pub. L. 72–304, 47 Stat. 725, enacted July 22, 1932, is a United States federal law passed under President Herbert Hoover in order to lower the cost of home ownership. It established the Federal Home Loan Bank Board to charter and supervise federal savings and loan institutions)* in 1981, whereby accounting rules were changed in favor of lenders, allowing them to avoid booking large losses and increasing liquidity in the secondary market (Mason, 2004; Lewis, 1989). Later, the Real Estate Mortgage Investment Conduit (REMIC) in 1986, increased the flexibility of issuers by allowing more legal freedom and investment in the mortgage-backed security market. Freddie Mac and Fannie Mae became the largest issuers for the developed secondary market. Private-label issuances increased from 2001 through 2007, but declined drastically in 2008.

Innovation in Mortgage Design

The unstable and high-inflation situation of the 1970s precipitated the innovation in the available types of mortgages. The regulatory environment limited the utility of variable-rate mortgages by controlling how much and when they could change which in turn affected their profit. In the beginning periods, traditional mortgages were more expensive than the total cost over time for borrowers. As regulators deregulated the mortgage market, Graduated Payment Mortgages (GPMs) and ARMs made their debuts in the late 1970s and early 1980s, respectively. As pointed out by McAndrews (2015), in January 1975, the Federal Reserve Bank of Boston hosted a well-known conference on "new mortgage designs" at Cambridge, Massachusetts, at which ARMs were among the topics discussed.

Alternative mortgages addressed the problem of high inflation for regular households and favored into a period of low inflation. In the late 1980s alternative mortgages flourished in its new atmosphere of growth. Unfortunately, ARMs became a cornerstone of predatory lending practices and errors in interest rate calculations overflowed. Many ARMs such as interest-only ARMs, option ARMs, hybrid ARMs enabled a riskier pool of borrowers to be financed at a higher interest rate, which in turn caused a greater risk. Currently, 5/1 ARMs are very popular. A 5/1 ARM, hence forth referred to as an adjustable rate mortgage, means that the loan will have a fixed interest rate for the first 5 years of payments and the initial interest rate on an ARM will be changed by the lending institution annually.

Piskorski and Seru 92018) argued that he rigidity of mortgage contracts and many other frictions in the design of the market and the intermediation sector hindered efforts to restructure household debt in the aftermath of the financial crisis. Lowering short-term interest rates to historic lows and introducing the Home Affordable Refinancing Program and the Home Affordable Modification Program had only had mixed success.

Other Changes

Straka (2000) argued that the 1974 Equal Credit Opportunity Act (ECOA), deriving from an anti-discrimination sociocultural trend, prohibited discrimination on the basis of race, color, religion, national origin, sex, marital status, age, or receipt of public assistance. In 2010, the Dodd-Frank Act gave the Consumer Financial Protection Bureau (CFPB) the power to enforce compliance with ECOA within its jurisdiction, and the CFPB soon adopted the disparate impacts doctrine ("effects test") to prove discrimination under ECOA.

A distinct, though related, change was the advent of automated underwriting, including automated evaluation of creditworthiness. These both significantly reduced costs for lenders and removed some of the subjectivity of loan officers' processes out of the assessment of creditworthiness (Straka, 2000). Although minute expressions of discrimination persisted, automated underwriting procedures made it easier for lenders to avoid the appearance of impropriety because of the anonymous nature of automated applications.

METHODOLOGY AND MODEL SPECIFICATION

Structural Break and Implication

As articulated by Nguyen (2018), modeling lengthy time series data, as in modeling stochastic processes, typically comprise structural breaks. Misspecification may occur when care is not taken to account for explanations for structural breaks (Chesnes, 2012). In addressing substantive issues in the monetary sector of the economy, the Central Bank frequently responds with countercyclical monetary policy techniques when structural breaks develop, typically resulting from the impact of economic shocks (i.e., financial crises). Hence, the synergy between structural breaks and policy rates is quite obvious.

To represent the sudden changes in the relationship in the regression parameters and define the spread, explaining the possible structural breaks, this analysis calculates the difference between the two time series, symbolized by SP_t. Since we perceive that the break is endogenous, we endogenously examine the data to test whether or not any structural break occurred in the trend between the two time series. To this end, to search endogenously for the possibility of any structural break in the relationship between the two time series, this study utilized Perron's (1997) endogenous unit root test function with the intercept, slope, and the trend dummy to test the hypothesis that the spread has a unit root.

$$SP_t = \mu + \theta DU + \alpha t + \gamma DT + \delta D(T_b) + \beta SP_{t-1} + \Sigma^k_{i=1} \Psi_i \Delta SP_{t-i} + v_t \qquad (1)$$

where "i_t" is the 5/1 adjustable mortgage rate and "r_t" is the Fed funds rate at time t. As defined above, z_t is an independent variable measuring the effect of the interaction between the structural break and the Fed funds rate. d_t is the above defined dummy variable. $\delta_0 + \rho_0 = \pi_0$ is the short-run effect (within the week after the change in the Fed funds rate). It is a priory expectation that $0 < \delta_0 + \rho_0 = \pi_0 \leq 1$. $\delta_0 + \rho_0 = \pi_0 < 1$ indicates sluggish adjustment or stickiness. $\delta_0 + \rho_0 = \pi_0 = 1$ represents a complete pass-through in the short run.

Theoretically, the ARDL method proposed by Pesaran et al. (1997) has been a valuable tool for testing for the presence of long-run relationships between time-series. The advantage of the ARDL model is its ability to estimate both the long-term and short-term model parameters without requiring a pre-testing to determine the order of the cointegration of the variables; thus, avoiding the problems posed by non-stationary time series. This pre-testing is particularly problematic in the unit-root cointegration literature where the power of the unit-root tests is typically very low, and there is a switch in the distribution function of the test statistics as one or more roots of the right-hand side variables process approach unity. Furthermore, the ARDL procedure is robust to small samples, allowing different optimal lags of variables.

However, Pereira and Maia-Filho (2013) argued that the bounds test is based on the assumption that variables are either I(0) or I(1). Therefore, it is prudent to determine the stationarity of the time series data. The most common testing procedures to test for stationarity of time series data are Kwiatkowski-Phillips-Schmidt-Shin and Phillips-Perron.

As to the empirical estimation, Enders (2015) suggested that the process to estimate the coefficients for equation (2) is to utilize the Akaike information criterion to select the largest values of n, m, s and w, deemed feasible; CUSUM test and CUSUM of Squares test are used to test for model stability. Breusch-Godfrey Serial Correlation Lagrange (LM) multiplier test is then used as diagnostic to test the hypothesis that the residuals $\{\varepsilon_t\}$ are white noise.

As articulated by Pereira and Maia-Filho (2013), given the estimation results for equation (2), the long- run effect or pass-through can be calculated as:

$$\Phi = \frac{\sum_{k=0}^{m} \delta_k + \sum_{l=0}^{s} \rho_l + \sum_{v=0}^{w} \pi_v}{1 - \sum_{j=1}^{n} \beta_j} \qquad (3)$$

As articulated by Berstein and Fuentes (2003), Φ should be positive and close to 1. $\Phi = 1$ implies a complete pass-through in the long-run. If $\Phi < 1$ or $\Phi > 1$, it implies either stickiness (less than perfect pass-through) or overshooting.

Additionally, this investigation studies the long-run relationship between the Fed funds rate and the adjustable mortgage in the residential housing market. To this end, this investigation follows Pereira and Maia-Filho (2013) to use the bounds testing approach (Pesaran, Shin, and Smith, 2001) for the following error correction representation of the Autoregressive Distributed Lag model:

$$\Delta i_t = \varphi + \sum_{j=1}^{n} \eta_j \Delta i_{t-j} + \sum_{k=0}^{m} \kappa_k \Delta i_{t-k} + \sum_{l=0}^{s} \omega_l \Delta z_{t-l} + \sum_{v=0}^{w} \pi_v \Delta d_{t-v} + \lambda_1 i_{t-1} + \lambda_2 r_{t-1} + \lambda_3 z_{t-1} + \lambda_4 d_{t-1} + \varepsilon_t \quad (4)$$

where Δ is difference operator and the null hypothesis of "non-existing of the long-run relationship" is stated as $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$. The relevant F-statistics for the joint significance of the λ's are calculated and compared with the critical values tabulated by Pesaran, Shin, and Smith (2001). If the estimated F-statistic is greater than the upper bound critical value, the variables are cointegrated. If it is below the lower bound, the null hypothesis cannot be rejected, i.e., there is no support evidence for long-run relationship between the Fed funds rates and the adjustable mortgage rates.

DATA

Since the U.S. Subprime mortgage crisis occurred during 2008, to empirically discern the aforementioned issues, this study uses the weekly federal funds rates r_t and the 5/1 adjustable mortgage rates i_t from January 5, 2005 through December 26, 2007 period, and January 7, 2009 through November 22, 2017 period, where the data is available, to estimate the autoregressive distributed lag model (1). The 5/1 adjustable mortgages are mortgages whose rates will stay the same for a 5- year introductory period. After this initial period, the interest rate could be adjusted annually. The sample periods were determined by the availability of data. All time-series data are collected from the FRED database of the Federal Reserve Bank of St. Louis. Additionally, from hence forth, the period from January 5, 2005 through December 26, 2007 is referred to as the pre-crisis period and the time from January 7, 2009 through November 22, 2017 is referred to as the post-crisis period.

For the pre-crisis period, the mean of the U.S. ARMs was 5.83 percent, and ranged from 4.99 percent to 6.39 percent with a standard error of 0.41 percent; the corresponding magnitudes for the post crisis period were 3.29 percent, 2.56 percent, 5.49 percent, and 0.64 percent, respectively. The mean of the federal funds rates over the prior crisis period was 4.40 percent, and ranged from 2.14 percent to 5.30 percent with a standard error of 0.95 percent; these figures for the post-crisis period were 0.24 percent, 0.05 percent, 1.16 percent, and 0.27 percent, respectively.

Additionally, the spread between these two rates in the pre-crisis sample was only 1.43 percent, and ranged from 0.62 percent to 2.89 percent with a standard error of 0.60 percent; the corresponding figures for the post-crisis period were 3.04 percent, 1.97 percent, 5.39 percent, and 0.71 percent, respectively. Interestingly, their correlation was 91.93 percent in the prior-crisis period and -0.07 in the post-crisis period.

EMPIRICAL RESULTS

The empirical results for this investigation are reported in the following sections.

The Degree of Cointegration

The bounds test is based on the assumption that variables are either I(0) or I(1). The most common testing procedures to test for stationarity of time series data are *Kwiatkowski-Phillips-Schmidt-Shin* (KPSS) and *Phillip-Perron (PP)*. The results of *Kwiatkowski-Phillips-Schmidt-Shin* and Phillips-Perron test of the adjustable mortgage rate, i_t, and the federal funds rate, r_t, are summarized in Exhibits 1-a and 1-b in the Appendix

Both of these testing procedures suggests that the adjustable mortgage rate, i_t, is I(1) ; while the Phillips-Perron testing procedure suggests that the federal funds rate, r_t, is I(1) and the Kwiatkowski-Phillips-Schmidt-Shin test indicates this rate is I(0) in the pre-crisis period. As for the post-crisis sample, both of these testing procedures suggests that the adjustable mortgage rate, i_t, is I(0) ; while the Phillips-Perron testing procedure suggests that the federal funds rate, r_t, is I(1) and the Kwiatkowski-Phillips-Schmidt-Shin test indicates this rate is I(0). Pereira and Maia-Filho (2013) argued that it is appropriate to use the bounds test to check for cointegration between the adjustable mortgage rate and federal funds rate in both sample periods.

Structural Breaks

This investigation defines the spread, R_t, as the difference between the adjustable mortgage rate i_t and the federal funds rate r_t. Perron's (1997) endogenous unit root test function with the intercept, slope, and the trend dummy is applied to the spread to endogenously search for structural breaks in the prior- and post-crisis periods. The estimation results are summarized in Exhibits 2-a and 2-b in the Appendix.

For the period prior to the crisis, the estimation results, reported in Exhibit 1-a, reveal that the post-break intercept dummy variable, *DU*, is negative; while the post-break slope dummy variable, DT, is positive and both are significant at any conventional level. The break dummy, $D(T_b)$is positive and is insignificant at the 10 percent level. The time trend, t, is negative and is significant at the 1 percent level. These results suggest that the spread follows a stationary trend process.

As for the post-crisis period, the empirical results, summarized in Exhibit 1-b, show that the post-break intercept dummy variable, *DU*, is negative and is insignificant; while the post-break slope dummy variable, DT, is positive and is significant at any conventional level. The break dummy, $D(T_b)$ is negative and is insignificant at the 10 percent level. The time trend, t, is negative and is significant at the 1 percent level. These results suggest that the spread follows a stationary trend process in the post-crisis period.

However, strength of the test statistic $t(a = 1) = -4.82275$ for the pre-crisis and which fails to confirm the structural break in the week including Wednesday, February 7, 2007 and $t(a = 1) = -4.62108$ which also fails to confirm the structural break in the week containing Wednesday, May 1, 2007. The Chow test was performed and the results confirmed the structural breaks in the weeks containing these Wednesdays.

The Autoregressive Distributed Lag (ARDL) Model

First for the pre-crisis sample period, as the methodology section confers, and, building upon the Akaike information criterion (AIC), the estimation process suggests that the optimal values are n = 3, m = 1, s = 5 and w = 5 as the values described for AIC in Exhibit 4-a infer, since the ARDL (3, 1, 5, 5) model has the lowest AIC value, it is applicable and therefore utilized in this analysis. The summarized results of estimation, and calculating diagnostic statistics for the autoregressive model, ARDL (3, 1, 5, 5), are presented in the following Exhibits 3-a, 4-a in the Appendix. Both the CUSUM and CUSUM of Squares Test and their bands of the 5 percent significance suggest that the estimated coefficients of the model is stable over the sample period.

For the post-crisis sample period, and again basing upon the Akaike information criterion (AIC), the estimation process suggests that the optimal values are n = 5, m = 5, s = 11 and w = 0 as the values of AIC in Exhibit 4-b indicates. Since the ARDL (5, 5, 11, 0) model has the lowest AIC value, it is utilized in this analysis. The summarized results of estimation, and calculating diagnostic statistics for the autoregressive model, ARDL (5, 5, 11, 0), are respectively presented in the following Exhibits 3-b, 4-b. Also, the CUSUM and CUSUM of Squares Test and their bands of the 5 percent significance indicate the stabilities of the estimated parameters of the model over the sample period.

The left section of Exhibit 4-a and 4-b respectively present the diagnostic test's analysis result in testing for correlations amongst the independent variables as well as the likelihood that the variance of the error term will depend upon estimated the model's regressors over the pre- and post-U.S. subprime mortgage crisis of 2008. The AIC-values of the four best-estimated models are also respectively reported in the right section of Exhibit 4-a and 4-b in the Appendix.

An analysis of the overall estimation results, using data in the period prior to the 2008 U.S. subprime mortgage crisis, indicates that there exists no serial correlation and that the model exhibits strong predictive power, as evidenced by the strength of the Breusch-Godfrey Serial Correlation Lagrange Multiplier Test $F_{(2,131)}$ = 0.295058, with the p-value being 0.7450. This result fails to reject the null hypothesis that there is no serial correlation in the residuals. Similarly, the estimation results from data in the post crisis period reveal that based on the Godfrey Serial Correlation Lagrange Multiplier Test $F_{(2,426)}$ = 0.641862, with the p-value being 0.5268 the null hypothesis of no serial correlation in the residuals could not be rejected at any conventional level of statistical significance.

Overall, the diagnostic analysis indicates that the estimated ARDL (3,1,5,5) model is fairly reliable for the period between January 5, 2005 and December 28, 2008. The empirical results also suggested that the estimated ARDL (5,5,11,0) model should be used to empirically investigate the issues of interest in the period between January 7, 2009 to November 22, 2017.

With regard to the short-run federal funds rate pass-through to the adjustable mortgage rate, Exhibit 3-a suggested that for the prior to crisis period, January 5, 2005 – December 28, 2007, the estimated sum of $\delta_0 + \rho_0 + \pi_0$ is 0.686655 (0.22693+ 0.579155 -0.11943 = 0.686655) for the prior to crisis period. Exhibit 3-b revealed that the short-run pass-through rate is $\delta_0 + \rho_0 + \pi_0$ = 0.093466 (0.289121 - 0.00576 - 0.18899 = 0.093466) for the period from January 7, 2009 to November 22, 2017.

In addition, based on the estimated equation (3) using data from January 5, 2005 to December 28, 2008, the following calculation indicates that the estimated long-run federal funds rate pass-through to the adjustable mortgage rate in the period prior to the subprime mortgage crisis is Φ = 1.190958.

$$\Phi = \frac{\sum_{k=0}^{m}\delta_k + \sum_{l=0}^{s}\rho_l + \sum_{v=0}^{w}\pi_v}{1-\sum_{j=1}^{n}\beta_j} = \frac{0.029688 + 0.076928 - 0.01254}{1-0.921009} = \frac{0.094075}{0.078991} = 1.190958$$

For the period after the crisis, data from the estimated equation (3) utilizing data from January 7, 2009 to November 22, 2017 was used to calculate the long-run pass through from the U.S. federal funds rate to the adjustable mortgage rate. The calculation results reveal that the pass-through rate $\Phi = 2.970562$.

$$\Phi = \frac{\sum_{k=0}^{m}\delta_k + \sum_{l=0}^{s}\rho_l + \sum_{v=0}^{w}\pi_v}{1-\sum_{j=1}^{n}\beta_j} = \frac{0.198462 + 0.033112 - 0.18899}{1-0.985665} = \frac{0.042583}{0.014335} = 2.970562$$

As to testing the null hypothesis of "non-existing of the long-run relationship $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$" for the pre-crisis period, the calculated value of the relevant F-statistic of 1.984698 is compared to the critical value of the lower bound I(0)= 2.92 and upper bound I(1) = 3.84. The result indicates that the null hypothesis of "non-existing of the long-run relationship" between the adjustable mortgage rate and the federal rate cannot be rejected at any level of significance. Failure to reject the null hypothesis suggests that there is no long-term relationship between U.S. adjustable mortgage rate and the federal funds rate during the pre-subprime mortgage crisis of 2008.

Finally, for the post-crisis period, the calculated value of the relevant F-statistic of 4.712226 is compared to the critical value of the lower bound I(0)= 2.92 and upper bound I(1) = 3.84. The result suggests that the null hypothesis of "non-existing of the long-run relationship-$H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$ " between the adjustable mortgage rate and the federal rate should be rejected at any level of significance. Reject the null hypothesis suggests that there is a long-term relationship between U.S. adjustable mortgage rate and the federal funds rate during the post-subprime mortgage crisis of 2008.

DISCUSSIONS OF THE EMPIRICAL RESULTS

To investigate whether the pass-through from federal funds rates to the adjustable mortgage rates before and after the U.S. subprime mortgage crisis and since the international crisis in 2008, two data samples on the weekly 5/1 adjustable mortgage rates and federal funds rates were collected from the FRED database of the Federal Reserve Bank of St. Louis. These samples were i_t from January 5, 2005 through December 26, 2007 period, and January 7, 2009 through November 22, 2017. The descriptive statistics derived from the two samples strongly suggest that the U.S. Subprime mortgage crisis of 2008 and the ensuing expansionary monetary policy in the near zero interest rate environment, including the quantitative easing as an extraordinary economic stimulus, have changed the nature of the pass-through from the federal funds rates to the adjustable mortgage rates. They also changed the pricing of the adjustable rate mortgages by lending institutions.

The investigation proceeded by the endogenous search process for breaks in the relationship between the federal funds rates and the adjustable mortgage rates in the two sample periods using Perron's (1997) endogenous unit root test function with the intercept, slope, and the trend dummy. The Perron's process identified and the Chow's test confirmed the structural break between the federal funds and the adjustable mortgage rates in the week containing Wednesday February 7, 2007 during the pre-crisis period and in the week including Wednesday May 1, 2013 in the post-crisis sample. To account for these structural breaks, this investigation introduced a dummy variable, d_t, and assigned the value of 1 from the week containing Wednesday February 7, 2007 and 0 elsewhere over the pre-crisis period and 1 from the week containing Wednesday May 1, 2013 and 0 elsewhere over the post-crisis period. Econometrically, this introduction of the dummy variable precipitated the generation of the interaction term between the dummy variable and the federal funds rate, which is captured by z_t, being an independent variable of the models to be estimated by the data.

The estimation results of the Autoregressive Distributed Lag model as specified by equation (2) using the data from the pre-crisis period suggested the best model is ARDL (3, 1, 5, 5). The estimated equation revealed that the short-run pass-through rate of the federal funds rate to the adjustable mortgage rate in the home mortgage market is $\delta_0 + \rho_0 + \pi_0$ is 0.686655. Based on the Akaike information criterion, the longest lag retained by the estimation process for the adjustable mortgage rate is 3 (i_{-3}) and for the federal funds rate is 1 (r_{-1}). These findings suggest that the U.S. commercial banks considered their adjustable mortgage rates three weeks back in determining their current adjustable mortgage rate; while these lending institutions took up to only one week to respond to the change in the targeted federal funds rate completely. Based on the estimation resulted reported in exhibit 3-a, the calculated long-run pass-through rate of the federal funds rate to the adjustable market rate on the home mortgage markets is $\Phi = 1.190958$. These empirical findings indicate that that the U.S. short-run pass through rate is relatively low and long-run rates of pass-through are relatively high as compared to empirical magnitudes reported in the literature in the emerging and advanced economies (Alencar, 2011; Pereira and Maia-Filho, 2013, Nguyen 2017, and 2018, Nguyen et al., 2017, Wickens and Breusch, 1988).

The empirical results for the post-crisis period suggested the best model is ARDL (5, 5, 11, 0), which is sharply different from results reported for the pre-crisis period. The estimated equation revealed that the short-run pass-through rate of the federal funds rate to the adjustable mortgage rate in the home mortgage market is $\delta_0 + \rho_0 + \pi_0 = 0.093466$. Based on the Akaike information criterion, the longest lag retained by the estimation process for the adjustable mortgage rate is 5 (i_{-5}) and for the federal funds rate is 5 (r_{-5}). These findings suggest that the U.S. commercial banks considered the their adjustable mortgage rates five weeks back in determining their current adjustable mortgage rate; while these lending institutions also took up to five weeks to respond to the change in the targeted federal funds rate completely. Based on the estimation resulted reported in exhibit 3-b, the calculated long-run pass-through rate of the federal funds rate to the adjustable market rate on the home mortgage markets is $\Phi = 2.970562$. These empirical findings indicate that that the U.S. short-run pass through rate is extremely low and long-run rates of pass-through are quite high as compared to empirical magnitudes reported in the literature in the emerging and advanced economies (Alencar, 2011; Pereira and Maia-Filho, 2013, Nguyen 2017, and 2018, Nguyen et al., 2017, Wickens and Breusch, 1988). The empirical results, especially the extremely low short-run pass through rate, may be attributable to condition of home mortgage markets, the impact of the subprime mortgage crisis and the countercyclical monetary policies in the near-zero rate environment.

As to the long-term relationship between the federal funds rate r_t and the adjustable mortgage rate i_t, this study investigates this issue by testing the above stated null hypothesis $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$ for the pre- and post-subprime mortgage crisis of 2008. The result suggests that this hypothesis of no long-term relationship between the federal funds rate r_t and the adjustable mortgage rate over the pre-crisis sample cannot be rejected. However, for the post-U.S. subprime mortgage crisis period, testing procedure suggests that the null hypothesis $H_0 : \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$ should be rejected at any conventional level of significance. Rejection of the null hypothesis indicates long-run relationship between the Central Bank's targeted federal funds rate r_t and the adjustable mortgage rate in the home mortgage markets, i_t, in the United States.

In short, the aforementioned descriptive statistics, responding time lags, pass-through from the federal funds rates to the adjustable mortgage rates, suggest that the lending institutions responded to the Federal Reserve System's countercyclical monetary policy, as reflected in changes in targeted federal funds rate, differently prior to and after the subprime mortgage crisis of 2008.

CONCLUSION

Historically, the United States has pursued a standing policy promoting home ownership through regulations and institutional arrangements. Consequently, in 2009, over sixty-seven percent (67.40) of American families own their own homes, and residential real estate is by far the largest investment for the average American as well as the largest component of individual wealth.

The OPEC's oil embargo against the United States and the countercyclical monetary policy targeting levels of market interest rates caused unprecedented inflation in the U.S. in the late 1970s and the early 1980s, precipitated drastic reactive deregulations in the banking industry in the early 1980s. These developments coupled with the well-known "borrowing short and lending long in thirty-year level-payment fixed-rate mortgage" modus operandi of the U.S. lending institutions since the 1930s led to a major banking crisis of 1980s causing bankruptcies of a significant number of commercial banks and more than a half of savings and loan association. The new economic reality of the 1980s made innovation in the available types of mortgages both necessary and inevitable—traditional mortgages, those with fixed rates and level payments—were assumed to be the gold standard well into the 1970's by both lenders and consumers alike. ARMs were introduced as the remedy for the "borrowing short and lending long" because ARMs allow lending institutions to match the maturities of their financial assets and liabilities, i.e., to follow the "borrowing short and lending short" modus operandi.

Even though these alternative mortgages addressed the problem of high inflation for regular households, they maintained their popularity into a period of low inflation. There was little response by regulators to the new environment of the late 1980's, and alternative mortgages were allowed to flourish. Unfortunately, as time passed, ARMs became a cornerstone of predatory lending practices and errors in interest rate calculations abounded. A wide variety of ARMs ensued, such as interest-only ARMs, option ARMs, hybrid ARMs, and so forth, all of which enabled a riskier pool of borrowers to be financed at a higher interest rate, increasing risk all around. These in turn contributed to the subprime mortgage crisis of 2008.

Moreover, the 2008 subprime mortgage crisis, the U.S. and most international economies resorted to extremely expansionary countercyclical monetary policy pushing nominal interest rates to almost zero to deal with their unemployment problems. Consequently, the monetary policy makers in these countries have been operating in the Zero Lower Bound or Zero Nominal Lower Bound interest rate environments. Zero Lower Bound is a macroeconomic problem that occurs when the short-term nominal interest rate is at or near zero, causing a liquidity trap and limiting the capacity that the central bank has to stimulate economic growth. Therefore, focus of this paper is to probe the question of how the U.S. commercial banks passed changes in their costs of funds due to changes in the federal funds rate to their adjustable rate mortgage borrowers before and after the subprime crisis.

To investigate the above issues, this study uses a before and an after subprime mortgage crisis samples of the weekly federal funds rates r_t and the adjustable mortgage rates i_t. The before crisis sample cover the period from January 5, 2005 through December 26, 2007 period, and the after crisis sample was from January 7, 2009 through November 22, 2017, where the data is available, to estimate the autoregressive distributed lag model. The statistics, responding time lags, pass-through from the federal funds rates to the adjustable mortgage rates, suggest that the lending institutions responded to the Federal Reserve System's countercyclical monetary policy, as reflected in changes in targeted federal funds rate, differently prior to and after the subprime mortgage crisis of 2008.

Additionally, the estimation results indicated that the average spread and the pass-through rates were higher in the post-crisis period, which may be attributable to the temperament of management of the lending institutions in the Zero Lower Bound interest rate environment. Theoretically, to increase market rates, the Federal Reserve must sell its financial assets (most of which were purchased through the QE program which were priced at low rates) which may reduce its profits and hence reducing its annual contributions to the federal governmental budgets. Additionally, higher U.S. interest rates would reduce investments, worsen trade deficit, increase the servicing costs of the national debts, and potentially affect employment, stock, and housing markets negatively. Therefore, the U.S. Zero Lower Bound interest rate environment is not expected to change soon.

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Exhibit 1-a: PP and KPSS Test Results, Weekly Data: Jan. 5, 2005 - Dec. 26, 2007

	Phillips-Perron		*Kwiatkowski-Phillips-Schmidt-Shin*	
Series	*Level*	*Differencing*	*Level*	*Differencing*
i_t	-1.936409n	-11.78300y	1.044028n	0.262743y
r_t	-2.892654n	-13.63584y	1.166050 y	1.546589y

Note: "n" and "y" *indicate whether the series is non- stationary and stationary at the 5 percent level.*

Exhibit 1-b: PP and KPSS Test Results, Weekly Data: Jan. 7, 2009 - Nov. 22, 2017

	Phillips-Perron		*Kwiatkowski-Phillips-Schmidt-Shin*	
Series	*Level*	*Differencing*	*Level*	*Differencing*
i_t	-4.239304^{y}	-23.17731^{y}	1.476510^{y}	0.971743^{y}
r_t	-2.149173^{n}	-15.20161^{y}	1.009471^{y}	0.222599^{y}

Note: "n" and "y" *indicate whether the series is non- stationary and stationary at the 5 percent level.*

Exhibit 2-a: Perron's Endogenous Unit Root Test: Jan. 5, 2005-Dec.26, 2007

$$PR_t = 1.11832 - 1.95397DU - 0.00766t + 0.01737DT + 0.09217D(T_b) + 0.56002PR_{t-1} + v_t$$

(4.50144*) (-4.71436*) (-4.40930*) (4.81155*) (1.00378) (49.95841*)

Number of augmented lags: $k = 12$ Break Date: Feb. 7, 2007 $t(a = 1) = -4.8227$

Note: Critical values for t-statistics in parentheses. Critical values based on n = 100 sample for the break date (Perron, 1997). "*" indicates significance at the 1 percent level.

Exhibit 2-b: Perron's Endogenous Unit Root Test,Data: Jan. 7, 2009-Nov. 22, 2017

$$PR_t = 0.35917 - 0.01827DU - 0.00085t + 0.00047DT + 0.05114D(T_b) + 0.92075PR_{t-1} + v_t$$

(4.35320*) (-0.65557) (-4.06634*) (2.85070*) (-0.82606) (53.68940*)

Number of augmented lags: $k = 9$ Break Date: May 1, 2013 $t(a = 1) = -4.62108$

Note: Critical values for t-statistics in parentheses. Critical values based on n = 100 sample for the break date (Perron, 1997). "*" indicates significance at the 1 percent level.

Exhibit 3-a: ARDL (3, 1, 5, 5) and Bounds Test, Data: Jan. 5, 2005 – Dec. 28, 2008

ARDL(3,1, 5, 5), dependent variable: i_t			**Bounds Test, dependent variable**: Δi_t		
Variable	Coefficient	t-statistic	Variable	Coefficient	t-statistic
i_{-1}	1.0059*	16.267	Δi_{-1}	0.0849	1.0863
i_{-2}	0.1637	1.7548	Δi_{-2}	0.2486*	3.1460
i_{-3}	-0.2486*	-3.1401	Δr_0	0.2269*	2.8795
r_0	0.2269**	2.4714	Δd_0	0.5792	0.9823
r_{-1}	-0.1972**	-2.2119	Δd_{-1}	0.0733	0.1445
d_{-0}	0.5792	0.9455	Δd_{-2}	-0.4856	-0.8990
d_{-1}	-0.4290	-0.6485	Δd_{-3}	-0.6271	-1.2905
d_{-2}	-0.5592	-1.322	Δd_{-4}	-1.322	-3.9069
d_{-3}	-0.1411	-0.5690	Δz_0	-0.1194	-1.0718
d_{-4}	-1.0702*	-4.8136	Δz_{-1}	-0.0159	-0.1656
d_{-5}	1.6973*	4.5930	Δz_{-2}	0.0811	0.7935
z_0	-0.1194	-1.0320	Δz_{-3}	0.1079	1.1752
z_{-1}	0.0910	0.7270	Δz_{-4}	0.3156*	3.8444
z_{-2}	0.0970	1.2107	i_{-1}	-0.0790*	-2.6552
z_{-3}	0.0268	0.5694	r_{-1}	0.0297**	2.1451
z_{-4}	0.2077*	4.9114	d_{-1}	0.0769	0.4173
z_{-5}	-0.3156	-4.5232	z_{-1}	-0.0125	-0.3489
constant	0.3296*	2.8664	*constant*	0.3296*	2.7547

$R^2 = 0.9839$ and $\bar{R}^2 = 0.9819$
F-value = 478.8337* and AIC = 2.9315

$R^2 = 0.28620$ and $\bar{R}^2 = 0.18886$
F-value = 2.9403*;
Bound Test F = 1.9847, k = 3

Note: "*", "**" and "***" indicate the 1 %t, the 5% and the 10% significance levels, respectively. Critical values for bounds tests at the 10%: I(0) = 2.74, I(1) = 3.31; the 5%: I(0) = 2.92, I(1) = 3.84; the 1%; I(0) = 3.91, I(1) = 5.04.

Exhibit 3-b: Estimation Results for ARDL (5, 5, 11, 0) and Bounds Test, Data: Jan. 7, 2009-Nov. 22, 2017

ARDL(5, 5, 11, 0), dependent variable: i_t			Bounds Test, dependent variable: Δi_t		
Variable	Coefficient	t-statistic	Variable	Coefficient	t-statistic
i_{-1}	0.888537*	14.89952	Δi_{-1}	-0.097128*	-2.086482
i_{-2}	0.151256*	2.605037	Δi_{-2}	0.054128	1.160757
i_{-3}	-0.157942*	-3.337249	Δi_{-3}	0.103814**	-2.298879
i_{-4}	-0.013460	-0.279501	Δi_{-4}	-0.117274*	-2.594967
i_{-5}	0.117274**	2.285107	Δr_{0}	0.289121**	2.235657
r_{0}	0.289121***	1.825509	Δr_{-1}	-0.010053	-0.105621
r_{-1}	-0.100712	-0.929967	Δr_{-2}	0.038150	0.394185
r_{-2}	0.048203	0.521425	Δr_{-3}	-0.039190	-0.414074
r_{-3}	-0.077340	-0.680218	Δr_{-4}	-0.300471*	-3.220334
r_{-4}	-0.261281**	-2.260108	Δd_{-0}	-0.005764	-0.104803
r_{-5}	0.300471*	4.212538	Δd_{-1}	0.015711	0.293877
d_{0}	-0.005764	-0.376456	Δd_{-2}	0.036015	0.674084
d_{-1}	-4.188867*	8.919256	Δd_{-3}	0.004325	0.080834
d_{-2}	0.143360*	4.165806	Δd_{-4}	0.020124	0.375906
d_{-3}	0.054588*	-7.284591	Δd_{-5}	0.087920	1.643548
d_{-4}	0.020304*	3.488634	Δd_{-6}	0.052776	0.984212
d_{-5}	-0.031690*	13.13621	Δd_{-7}	-0.004560	-0.085128
d_{-6}	0.015798*	-9.195066	Δd_{-8}	0.294147*	5.498274
d_{-7}	0.067796*	-16.73064	Δd_{-9}	0.065451	1.185867
d_{-8}	-0.035143*	78.76176	Δd_{-10}	0.153873	2.796353
d_{-9}	-0.057336*	-12.87693	i_{-1}	-0.014336*	-2.800067
d_{-10}	0.298707*	5.150786	r_{-1}	0.198462**	2.028940
d_{-11}	-0.228696*	-11.12516	d_{-1}	0.033114**	2.235003
z_{0}	0.088421	-1.626119	z_{-1}	-0.188991***	-1.933423
constant	-0.153873	0.400148	*constant*	0.008002	0.405911

$R^2 = 0.991821$ and $\bar{R}^2 = 0.991362$ $R^2 = 0.655893$ and $\bar{R}^2 = 0.617120$

F-value = 2,162.534* and AIC = -2.979487 F-value = 21.2624*

Bound Test F = 4.712226, k = 3

Note: "*", "**" and "***" indicate the 1 percent, the 5 percent and the 10 percent significance levels, respectively. Critical values for bounds tests at the 10 percent: I(0) = 2.47, I(1) = 3.31; the 5 percent: I(0) = 2.92, I(1) = 3.84; the 1 percent: I(0) = 3.91, I(1) = 5.04.

Exhibit 4-a: Diagnostic Tests and the Four Best Models, Prior-Crisis Period

Diagnostic Test	Model Selection Criteria	
	Five Best *Models*	*AIC*
Breusch-Godfrey Serial Correlation LM Test: H_0: There is no serial correlation in the residuals. $F_{(2,131)}$ = 0.295058, p-value = 0.7450	***ARDL (3,1,5,5)***	***-2.93496***
	ARDL (3,2,5,5)	-2.92966
	ARDL (4,1,5,5)	-2.92933
	ARDL (4,2,5,5)	-2.92625

Note: data is from calculations by authors.

Exhibit 4-b: Diagnostic Tests and the Four Best Models, Post-Crisis Period

Diagnostic Test	Model Selection Criteria	
	Five Best *Models*	*AIC*
Breusch-Godfrey Serial Correlation LM Test: H_0: There is no serial correlation in the residuals. $F_{(2,426)}$ = 0.641862, p-value = 0.5268	***ARDL (5,5,11,0)***	***-2.97712***
	ARDL (11,5,11,0)	-2.97604
	ARDL (5,5,12,0)	-2.97388
	ARDL (10,5,11,0)	-2.97345

Note: data is from calculations by authors.