Three Essays on Empirical Macroeconomics and Financial Markets

By

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Submitted to the graduate degree program in Economics and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

This dissertation consists of three essays on empirical macroeconomics and financial markets in the United States. Although they can be considered as three independent essays, their findings are connected with each other in some way. For example, all three essays support a point of view that in empirical research, carefully investigating any abnormal changes in the data is important and sometimes can be a breakthrough. The first essay investigates the incorrect calculation of nonborrowed reserves and finds that it should account for the unclear indications of the Federal Reserve's monetary policy. The second essay finds that the repurchase agreement rates (repo rates) can better forecast monetary policy by ignoring recent abnormal data. This finding further supports the first essay's point of view that good quality data is very import for the clear indications of the Federal Reserve's monetary policy. The third essay finds that 3-month Treasury bill rates were not sensitive to the discount rate changes during the "Great Recession", since the discount rate was above the federal funds rate during that period of time, which never occurred before in the U.S. history and caused the discount window borrowing to lose its function.

The first essay investigates the nonborrowed reserves calculations and finds that the accounting method for calculating nonborrowed reserves has recently changed with an inaccurate result. This paper tries different ways to correct nonborrowed reserves and explores the implications of monetary policy. These experiments show the robustness of the well-structured semi-VAR model developed by Bernanke and Mihov (1995), since in this model, bad data never works as well as good data; doctored data never works as well as real

data. Furthermore, this paper finds that the best indicator of monetary policy is still the federal funds rate. The inaccurate nonborrowed reserves calculation is at least one of the reasons which accounts for the unclear indications of the Federal Reserve's monetary policy during the recent financial crisis.

The second essay tests the performance of expectation theory by using various repo rates and Treasury bill rates and explores whether repo rates have more significant forecasting power for monetary policy than Treasury bill rates. Since the recent financial crisis created so much abnormal data, which may influence the forecasting result, this paper will also compare the forecasting ability between various repo rates and Treasury bill rates by ignoring the recent data. As a result, the forecasting performances are improved, just as expected. In fact, this paper finds the use of 3-month repo rates for forecasting federal funds rates is extremely strong. Furthermore, this paper will test and compare the forecasting ability of the government, agency and mortgage repo rates and explore whether any of these three repo rates can be considered as a better riskless rate than Treasury bill rates.

The third essay explores the market response to the discount rate changes during the recent U.S. recessions and finds that the response of market rates to discount rate changes varied during the recent two recessions. The different responses of market rates to discount rate changes are due to the various economic and policy circumstances that the market was facing. This conclusion is consistent with Thornton's finding (1998). Thornton (1998) found that the different market responses to the discount rate changes mainly depend on the information content that people believed contained in the announcements of the discount rate changes. It's interesting to point out that during the "Great Recession", market rates were not sensitive to discount rate changes. The underlying reason was the discount rates were above the federal funds rates during the "Great Recession". In other words, the discount window borrowing has lost its function to provide adequate funds to the economy during the recession.

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ABSTRACT

A considerable amount of research has explored the indicator for the Federal Reserve's monetary policy and the reactions of macro-economic variables to this monetary policy. Few existing works explore the Federal Reserve data that was used for measuring monetary policy. This paper investigates the nonborrowed reserves calculation and finds that the accounting method for calculating nonborrowed reserves has changed in an inaccurate way recently. This paper tries different ways to correct nonborrowed reserves and explores the indications of the monetary policy. These experiments show the robustness of the well-structured semi-VAR model developed by Bernanke and Mihov (1995), since in this model, bad data never works as well as good data; doctored data never works as well as real data. Furthermore, this paper finds that the best indicator of monetary policy is still the federal funds rate. The inaccurate nonborrowed reserves calculation is at least one of the reasons which accounts for the unclear indications of the Federal Reserve's monetary policy during the recent financial crisis.

1.1 Background

1.1.1 Inaccurate data in the Fed

1.1.1.1 Abnormal nonborrowed reserves

Suddenly on January, 1st, 2008, the nonborrowed reserves of U.S. banks became negative. Then they increased to as large as 486 billion in June, 2009 (figure1.1).

First of all, this was the first time nonborrowed reserves had been in a negative number. How can borrowed reserves exceed total reserves? It is an accounting error. A simple example: If there is a 6 inch apple pie on the table, what the Federal Reserve was doing was taking an 8 inch apple pie from the original one.

Secondly, the large increase in nonborrowed reserves later was due to the fact that total reserve was expanded by the Federal Reserve, but the Fed was still using an inaccurate accounting method which failed to include all the Term Auction Facility (TAF) borrowing in the total reserves.

1.1.1.2 Poor monetary-aggregate data

The Federal Reserve still uses the simple sum monetary aggregate data rather than Divisia index monetary aggregate data which has already been applied by many other countries. Simple sum aggregate data is inaccurate. You can not compare apples to oranges. The Federal Reserve cannot combine money in the checking account to savings account, since they have different costs known as the "user cost".[1] It costs more to hold the money in a checking account than in a savings account. The bank has to be compensated for providing extra liquidity if one holds money in a checking account.

1.1.1.3 No pre-sweeps data

Barnett (2010) pointed out that M1 aggregates are far below actual data. Banks only

[1] See Barnett and Serletis (2000) for "the user cost of money".

provide the Federal Reserve post-sweeps checking account data but no pre-sweeps data. In order to provide the Federal Reserve with less required reserves, banks usually transfer checking account deposits into savings account. In this case, the Federal Reserve is not able to monitor the exact liquidity, since money in the checking accounts is one of the most important channels to provide liquidity. To be accurate, they should have both pre-sweeps and post-sweeps data.

1.1.2 The Fed and the financial crisis

Both Barnett and Chauvet (2011) and Taylor (2008) showed that the monetary excesses were the main cause of the recent financial crisis. Furthermore, Hanke (2011) has updated the recent data and pointed out that no money supply (Divisia M4) and a very "weak" economy will not give us much confidence in the economy at least in the near future.

Barnett and Chauvet (2011) checked the Federal Reserve's simple sum monetary aggregate data and found it is far biased from index number theory, which misled both the public and the Fed's policy to take more risks and provide the market excess money before the recent financial crisis. In consequence, it might be a main cause of the recent sub-prime mortgage crisis.

Taylor (2008) found empirical evidence that government interventions caused the sub-prime mortgage crisis. The Federal Reserve set the interest rate deviating from the historical principles and thus provided the market with excess money.

Although Taylor (2008) did not explain in his paper why the Federal Reserve set the interest rate so low before the financial crisis, one of the underlying reasons can be that the Fed's faulty simple sum monetary aggregate data was far biased from the actual monetary aggregate data. By monitoring the inaccurate simple sum monetary aggregate data, the Federal Reserve set the federal funds rates so low than it should be. In other words, the Fed provided the market excess money before the sub-prime mortgage crisis, which is consistent with Barnett and Chauvet's findings (2011).

Hanke (2011) has updated the recent Divisia M4 data and pointed out that the money supply growth data M2 published by the Board of Governors of the Federal Reserve System has grown rapidly. While the Divisia M2 has decreased, the broader money measurement M4 decreased even more rapidly and is now currently flat. No money supply (Divisia M4) and a very "weak" economy will not give us much confidence in the economy at least in the near future. Once again, the Federal Reserve has misled both the public and itself by using the simple-sum monetary aggregate data M2.

1.1.3 The importance of high quality data in the "information age"

Information is more important today than ever, since we are in the "information age", especially when the internet is so widely used and so many portable wireless devises are invented. Let's take stock market as an example. Stock price may respond to various information shocks. As an investor, the first thing to do is to collect the correct information quickly and analyze how the market will respond to those information shocks and then make an appropriate decision. Before the internet was widely created, people could only trade at a certain place such as the New York Exchange. However, now one can sit at home in Shanghai and trade U.S. stock just by clicking a "buy" or "sell" button on an e-trading platform such as "Scottrade". High quality data and information is so valuable today, people have to pay thousands of dollars to get them. If one wants to get the repo rates data, the only place that provides that historical data so far as I know is the Bloomberg system. However, it is not free.

"In economic theory, the economic system is highly sensitive to information shocks."[2] The economic system's dynamics could be hurt by even the irrelevant information shocks.

[2] See Barnett (2012).

1.1.4 The Term Auction Facility

The Term Auction Facility (TAF) was established on December 12, 2007. It allowed the Federal Reserve to provide funds to depository institutions. First of all, banks were not willing to borrow from the discount windows, because that would signal the bank's insolvency. Secondly, since the Federal Reserve used a new method in setting the discount rate (the rate used when banks borrow at the discount window) since 2003, which thus became the first time in the U.S. history that the discount rates were higher than the federal funds rates during a recession, which will cause an even worse liquidity problem. Thirdly, the credit was so tight at the recent financial crisis; banks were not willing to lend to one another. TAF borrowing was established to accommodate the unique problem of the recent financial crisis.

The TAF provides banks with other benefits as well. For instance, the TAF allows banks to borrow against a wide range of collaterals. Moreover, the TAF has the potential to lower a bank's overall funding cost.

1.2 Motivation and Goal

It is the first time nonborrowed reserves have been in negative (figure1.1) since 1959.

The formula the Federal Reserve used to calculate nonborrowed reserves up to December 12, 2007 was:

Nonborrowed reserves = Total reserves – Discount Window Borrowings

Then on December 12, 2007, the Federal Reserve started using the following formula:

$$\text{Nonborrowed reserves} = \text{Total reserves} - \text{Discount Window Borrowings} \\ - \text{TAF borrowing}$$

The negative value of nonborrowed reserves was because total borrowings were larger than the total reserves. Not all TAF borrowing was included in total reserves, thus negative nonborrowed reserves occurred. I have sent e-mails to the Federal Reserve asking how much TAF borrowing was hold in total reserves. Unfortunately, the staff at the Federal Reserve could not give me a satisfactory answer.

If the Federal Reserve changed the accounting method for nonborrowed reserves intentionally, then did they also change the monetary policy indicator? Although the Federal Reserve claimed that the federal funds rate is used as the monetary policy instrument, the Federal Reserve does not always do as it says. Thus it makes sense to recheck the monetary policy indicator. How does the policy stance today compare with what it was in earlier periods? Furthermore, this paper will use the corrected nonborrowed reserves and re-evaluate various implications of the monetary policy. Last but not least, this paper will be an additional support for Barnett's proposal (2012) for creating the Fed's own data bureau by examining another Federal Reserve's inaccurate data.

1.3 Literature Review

1.3.1 Relevant methodology

Bernanke and his coauthors had a series of papers in exploring a good indicator of monetary policy actions.

Bernanke and Blinder (1992) found that the federal funds rate is very informative about future movements of real macroeconomic variables. The federal funds rate was found to be a good indicator of monetary policy actions.

Bernanke and Mihov (1995) developed a VAR-based methodology for measuring the stance of monetary policy by applying and extending the approach of Strongin (1992), Bernanke and Blinder (1992), and Christano, Eichenbaum, and Evans (1994). Bernanke and Blinder (1992) used structural VAR model to study the relationships among money, credit and income. Strongin (1992) proposed a new method of identifying monetary policy by using nonborrowed reserves.

Bernanke and Mihov (1995) developed a "semi-structural" VAR approach, which makes restrictions on policy block but leaves the macroeconomic variables unrestricted. The methodology nests earlier VAR-based measures and can be used to choose the best monetary policy indicator for macro economics. By using this model, Bernanke and Mihov (1995) successfully found that during 1979 to1982, the nonborrowed reserve model was strongly accepted, which suggested that nonborrowed reserve is the best indicator for monetary policy. This period overlaps Volcker's experimental nonborrowed reserve targeting period exactly.

Bernanke and Mihov (1998) further applied a "semi-structural" VAR model for exploring monetary policy's effects on macroeconomic variables.

1.3.2 The effects of the Federal Reserve's faulty data on financial crisis

Both Barnett and Chauvet (2011) and Taylor (2008) showed that the monetary excesses were the main cause of recent financial crisis. Barnett and Chauvet (2011) checked the Federal Reserve's simple sum monetary aggregate data and found it is far deviated from index number theory, which misled both the public and the Federal Reserve's policy to take more risks and provide the market with excess money before the recent financial crisis. In consequence, it may have contributed to the recent sub-prime mortgage crisis. Taylor (2008) found empirical evidence that government interventions caused the sub-prime mortgage crisis. The Federal Reserve set the interest rate deviating from the historical principles and thus provided the market with excess money. Although Taylor (2008) did not explain why the Federal Reserve set the interest rate so low before the financial crisis, one of the underlying reasons can be the Fed's faulty simple-sum monetary aggregate data misled the Fed's decision on setting the low federal funds rate, which is consistent with Barnett and Chauvet (2011)'s findings.

Furthermore, Hanke (2011) has updated the recent Divisia M4 data and pointed out that the money supply growth data M2 published by the Board of Governors of the Federal Reserve System has grown rapidly. While the DIvisia M2 has decreased, the broader money measurement M4 decreased even more rapidly and is now currently flat. No money supply (Divisia M4) and a very "weak" economy will not give us much confidence in the economy at least in the near future. Once again, the Federal Reserve has misled both the public and itself by using the simple-sum monetary aggregate data M2.

1.4 Methodology

This paper will use semi-structural VAR methodology developed by Bernanke and Mihov in 1995. The so called "Semi-structural VAR" means that half of the model is unrestricted, while the remaining half is restricted. In particular, the semi-structural VAR model which this paper is going to apply imposes restriction on block of policy indicators and no restrictions on macroeconomic variables. How to impose appropriate restrictions on block of policy indicators is extremely important. The effectiveness of this semi-structural VAR comes from the success of imposing the specific restrictions on these policy indicators. In order to do this, Bernanke and Mihov (1995) made a progress in exploring the underlying relationships and connections among policy indicators, which made this VAR model closer to the real world and thus more applicable.

(1) $$\boldsymbol{Y}_t = \sum_{i=0}^{k} \boldsymbol{B}_i \boldsymbol{Y}_{t-i} + \sum_{i=1}^{k} \boldsymbol{C}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^y \boldsymbol{v}_t^y$$

(2) $$\boldsymbol{P}_t = \sum_{i=0}^{k} \boldsymbol{D}_i \boldsymbol{Y}_{t-i} + \sum_{i=0}^{k} \boldsymbol{G}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^p \boldsymbol{v}_t^p .$$

"**Y**" are vectors of macroeconomic variables including real GDP, GDP deflator and consumer-price-index for all urban consumers.

"**P**" are policy indicators containing federal funds rate, total reserves and nonborrowed reserves.

Equation (1) represents that the macroeconomic variables depend on current, lagged values of macroeconomic variables and lagged values of policy indicators. In other words, policy indicators have no contemporaneous effect on macroeconomic variables. $\boldsymbol{v}^y$ are structural error terms. $\boldsymbol{A}^y$ is a general matrix.

Equation (2) expresses that the policy variables depend on both current and lagged values of policy variables and macroeconomic variables. This model assumes macroeconomic variables have contemporaneous effect on policy indicators. $\boldsymbol{v}^p$ are structural error terms.

We can rewrite equation (2) into the following,

$$(3) \qquad \boldsymbol{P}_t = \sum_{i=0}^{k} \boldsymbol{D}_i \boldsymbol{Y}_{t-i} + \sum_{i=1}^{k} \boldsymbol{G}_i \boldsymbol{P}_{t-i} + \boldsymbol{G}_0 \boldsymbol{P}_t + \boldsymbol{A}^p \boldsymbol{v}_t^p$$

$$\Rightarrow \quad (4) \qquad \boldsymbol{P}_t(\boldsymbol{I} - \boldsymbol{G}_0) = \sum_{i=0}^{k} \boldsymbol{D}_i \boldsymbol{Y}_{t-i} + \sum_{i=1}^{k} \boldsymbol{G}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^p \boldsymbol{v}_t^p$$

Assume $\boldsymbol{u}_t^p$ is the VAR residuals in the policy block. From equation (4), we can get

$$(5) \qquad \boldsymbol{u}_t^p = (\boldsymbol{I} - \boldsymbol{G}_0)^{-1} \boldsymbol{A}^p \boldsymbol{v}_t^p,$$

By rewriting equation (5) and dropping both subscripts and superscripts, equation (6) is derived:

$$(6) \qquad \boldsymbol{u} = \boldsymbol{G}\boldsymbol{u} + \boldsymbol{A}\boldsymbol{v}.$$

Equation (6) connects observable VAR residuals $\boldsymbol{u}$ and unobserved structural shocks $\boldsymbol{v}$ together.

1.5 Models

In order to connect the observable VAR residuals and the unobservable shocks in the policy block, a specific model is needed. Bernanke and Mihov (1995) used a standard and basic model of the market for bank reserves and the Fedederal Reserve's operating procedure.

μ is the observable VAR residual. ν is the unobservable shock. The market for bank reserves is expressed in the following equations from (7) to (9):

(7) $u_{TR} = -\alpha u_{FFR} + \nu^{d}$

(8) $u_{BR} = \beta(u_{FFR} - u_{DISC}) + \nu^{b}$

(9) $u_{NBR} = \phi^{d}\nu^{d} + \phi^{b}\nu^{b} + \nu^{s}.$

Equations (7) through (9) are all in the innovation forms and in the form of equation (6).

Equation (7) expresses that the demand for total reserves has a negative relationship with federal funds rate and a demand shock. This equation explains the market behavior of borrowing at the federal funds market.

Equation (8) represents that the demand for borrowed reserves has a positive relationship with federal funds rate, since borrowed reserves can be lent to other banks at the federal funds rate. Thus, banks are willing to borrow more from the discount window, if the federal funds rate is higher. At the same time, the demand for borrowed reserves correlates negatively on the discount rate and a disturbance. This equation explains the market behavior of borrowing at the discount window.

Equation (9) represents the Federal Reserve's behavior. Bernanke and Mihov (1995) assume that the Federal Reserve reacts to both demand for total reserve shocks and borrowed reserve shocks. The strength of the response is denoted as ϕ^{d} and ϕ^{b}. It makes sense to assume the Federal Reserve's response to those two demands, since the Federal

Reserve monitors the total reserves and borrowed reserves all the time. ν^s is the policy shock.

By rewriting equation (6) , equation (10) can be derived:

(10) $$\boldsymbol{u} = (\boldsymbol{I}-\boldsymbol{G})^{-1}\boldsymbol{A}\boldsymbol{\nu},$$

Where

$\boldsymbol{u}' = [\,\mathrm{u}_{TR} \quad \mathrm{u}_{NBR} \quad \mathrm{u}_{FFR}\,]$ $\quad \boldsymbol{\nu}' = [\nu^d \quad \nu^s \quad \nu^b]$

The matrix can be written out, by solving for equation (7) through (9).

$$(\boldsymbol{I}-\boldsymbol{G})^{-1}\boldsymbol{A} = \begin{bmatrix} -(\frac{\alpha}{\alpha+\beta})(1-\phi^d)+1 & \frac{\alpha}{\alpha+\beta} & (\frac{\alpha}{\alpha+\beta})(1+\phi^b) \\ \phi^d & 1 & \phi^b \\ (\frac{1}{\alpha+\beta})(1-\phi^d) & -\frac{1}{\alpha+\beta} & -(\frac{1}{\alpha+\beta})(1+\phi^b) \end{bmatrix} \quad (11)$$

The equation (10) has seven unknown parameters (α,β,ϕ^d,ϕ^b, variances of v^d,v^s, v^b). However, it has only six covariances[3]. Thus, it is under-identified by one restriction. Bernanke and Mihov (1995) further consider five alternative models to impose further restrictions on this under-identified model. The first four models impose two additional restrictions, which makes the model over-identified. The fifth model imposes only one restriction, which leaves the model just-identified.

By rearranging equation (11), we can get equation (12):

$$\nu^s = -(\phi^d+\phi^b)\mu_{TR} + (1+\phi^b)\mu_{NBR} - (\alpha\phi^d - \beta\phi^b)\mu_{FFR} \quad (12)$$

[3] Six covariances: $\mathrm{cov}(u_{TR}u_{TR}), \mathrm{cov}(u_{TR}u_{NBR}), \mathrm{cov}(u_{TR}u_{FFR}), \mathrm{cov}(u_{NBR}u_{NBR}), \mathrm{cov}(u_{NBR}u_{FFR})$ and $\mathrm{cov}(u_{FFR}u_{FFR})$.

Equation (12) expresses that monetary policy shock v^s depends on innovations in total reserves, nonborrowed reserves, and federal funds rates without further restrictions.

The differences of following five models depend on how the assumptions are made on the parameters. We can plug the assumed parameters in equation (12) and get the newly derived monetary policy shock $v^{s.}$

The first model is called federal funds rate model, which was established by Bernanke and Blinder (1992). They assume $\phi^d = 1$ and $\phi^b = -1$. The Federal Reserve targets the federal funds rate, so it completely offsets shocks to demand for both total reserves and borrowing at the discount window. Equation (12) becomes $v_s = -(\alpha + \beta)\mu_{FFR}$. The monetary policy shock only comes from the innovation of federal funds rate, since in the federal funds rate model, the federal funds rate is the only monetary policy instrument by assumption.

Equation (11) becomes:

$$(\boldsymbol{I} - \boldsymbol{G})^{-1}\boldsymbol{A} = \begin{bmatrix} 1 & \frac{\alpha}{\alpha+\beta} & 0 \\ 1 & 1 & -1 \\ 0 & -\frac{1}{\alpha+\beta} & 0 \end{bmatrix} \qquad (12)$$

The second model is called nonborrowed reserves model. Christiano and Eichenbaum (1991) developed this model by assuming that the nonborrowed reserves react solely to shocks of monetary policy. The implied restrictions are $\phi^d = 0, \phi^b = 0$. In this case, monetary policy shock becomes $v_s = \mu_{NBR}$. The monetary policy shock is from the innovation of nonborrowed reserve.

Equation (11) can be written as:

$$\boldsymbol{(I-G)^{-1}A}=\begin{bmatrix} -(\frac{\alpha}{\alpha+\beta})+1 & \frac{\alpha}{\alpha+\beta} & \frac{\alpha}{\alpha+\beta} \\ 0 & 1 & 0 \\ (\frac{1}{\alpha+\beta}) & -\frac{1}{\alpha+\beta} & -(\frac{1}{\alpha+\beta}) \end{bmatrix} \qquad (13)$$

The third model is the orthogonalized nonborrowed reserves created by Strongin (1992). He assumes that the shocks to total reserves are only demand shocks. Thus the restriction becomes $\alpha = 0, \phi^b = 0$.

Equation (11) now becomes:

$$\boldsymbol{(I-G)^{-1}A}=\begin{bmatrix} 1 & 0 & 0 \\ \phi^d & 1 & 0 \\ \frac{1}{\beta}(1-\phi^d) & -\frac{1}{\beta} & -\frac{1}{\beta} \end{bmatrix} \qquad (14)$$

The fourth model is the borrowed reserves model. The Fed targets the borrowed reserves sometimes. So the implied restriction is $\phi^d = 1, \phi^b = \alpha/\beta$. This model was developed by Cosimano and Sheehan (1994).

Equation (11) takes the form of:

$$\boldsymbol{(I-G)^{-1}A}=\begin{bmatrix} 1 & \frac{\alpha}{\alpha+\beta} & \frac{\alpha}{\beta} \\ 1 & 1 & \frac{\alpha}{\beta} \\ 0 & -\frac{1}{\alpha+\beta} & -\frac{1}{\beta} \end{bmatrix} \qquad (15)$$

The fifth model is the just identified model. Strongin (1992) assumes that the demand for total reserves is not elastic at all in a short period of time, so $\alpha = 0$.

Equation (11) can be further written out specifically as:

$$(\boldsymbol{I}-\boldsymbol{G})^{-1}\boldsymbol{A}=\begin{bmatrix} 1 & 0 & 0 \\ \phi^{d} & 1 & \phi^{b} \\ \frac{1}{\beta}(1-\phi^{d}) & -\frac{1}{\beta} & -\frac{1}{\beta}(1+\phi^{b}) \end{bmatrix} \qquad (16)$$

1.6 Data

This paper uses quarterly data from the first quarter of 1959 to the third quarter of 2009. The six variables are the real GDP, GDP deflator (implicit price deflator for GDP), federal funds (effective) rate, consumer-price-index for all urban consumers (all items), total reserves, and nonborrowed reserves of depository institution, respectively.

The six variables that Bernanke and Mihov (1998) used are the same as the variables used in this study, except for the fact that Dow--Jones index of spot commodity price was used instead of consumer price index for all urban consumers (all items).

This study tested 11, 12 and 13 lags for the sample period of first quarter of 1959 to the fourth quarter of 2007. Both AIC and SBS selected the 13 lags VAR model.

To determine the break point, both the record data and structural break test were used. Historical record shows that, first of all, Bernanke became chairman of Federal Reserve Board in 2006. Secondly, sub-prime mortgage crisis became apparent in 2007 and the National Bureau of Economic Research (NBER) defines that sub-prime mortgage crisis started at the end of December, 2007. Last but not least, nonborrowed reserves became negative in 2008 and the global financial crisis came to the forefront of the business world in September, 2008. From structural break tests, multiple structural change tests for nonborrowed reserves were performed. The result shows it is a partial structural change model with one break. From the graph (figure1.1) we can see that the break point should be somewhere around 2007. Everything being considered, 2007 was used as the break point.

1.7 Estimation and implications

The Semi-VAR methodology was applied for all the five models to test 1965-1996, 1965-2007 and 1965-2009 sample periods, respectively. The five models were introduced earlier in section 1.5. They are federal funds rate model (FFR), nonborrowed reserves model (NBR), orthogonalized nonborrowed reserves (NBR/TR), borrowed reserves model (BR) and just identified model (JI) respectively.

1.7.1 Estimation results

Table 1.1: Parameter Estimates for period 1965-1996 Models (Quarterly)

Model	α	β	ϕ^d	ϕ^b
FFR	-0.002075740 (0.001350056)	0.000943342 (0.001115339)	1	-1
NBR	-0.000018322 (0.000117240)	0.000165403 (0.000668353)	0	0
NBR/TR	0	**0.001216** (0.000000)	**1.968312** (0.000000) **[0.00000000]**	0
BR	**-0.0853** (7.4809e-10)	**0.1305** (6.9358e-10)	1	α/β
JI	0	**-0.000932783** (0.000287298)	**-0.254107725** (0.107767995) **[0.01837792]**	**-0.787284961** (0.037088054)

Table 1.2: Parameter Estimates for period 1965-2007 Models (Quarterly)

Model	α	β	ϕ^d	ϕ^b
FFR	-0.0002 (0.0006)	0.0005 (0.001)	1	-1
NBR	-0.0009 (0.0008)	0.0001 (0.0006)	0	0
NBR/TR	0	-0.0008 (0.0005)	-0.05 (0.083)	0
BR	0.0003 (0.0004)	-0.0006 (0.0007)	1	α / β
JI	0	**-0.0006** (0.0002)	**-0.152** (0.043)	**-0.73** (0.033)

Table 1.3: Parameter Estimates for period 1965-2009 Models (Quarterly)

Model	α	β	ϕ^d	ϕ^b
FFR	**-0.05** (0.002)	-0.0005 (0.0002)	1	-1
NBR	**-0.006** (0.001)	**-0.012** (0.002)	0	0
NBR/TR	0	**-0.046** (0.005)	**3.042** (0.132)	0
BR	**-0.030** (0.002)	**0.030** (0.002)	1	α/β
JI	0	**-0.151** (0.0002)	0.480 (0.432)	-3.01 (1.79)

The data in bold indicates that the coefficients are significantly different from zero (P value < 0.05). ϕ^d is the coefficient that describes the Fedederal Reserve's tendency to accommodate reserve demand shocks. We can get the estimates of ϕ^d from the third model and the last model. In the sample period between 1965 and 1996, this coefficient is estimated to be 1.968312 and -0.2541 respectively. But the 1.968312 has a higher statistical significance level, implying over accommodation of reserves demand shocks

($\phi^d = 1$). This estimation outcome contradicts the nonborrowed reserves (NBR) model, which assumes that $\phi^d = 0$. In consequence, the nonborrowed reserve (NBR) model is strongly rejected in this sample period. (See table 1.1)

During the sample period between 1965 and 2009, ϕ^d is estimated to be 3.042 and 0.480. Because 0.480 is not significantly different from zero, it is ignored. 3.042 indicates Federal Reserve's over-accommodation of reserve demand shocks, which implies that the nonborrowed reserve (NBR) model is strongly rejected. (See table 1.3)

In Bernanke and Mihov's study (1998), they found that the only period that accepts the nonborrowed reserve model is during 1979 and 1982.This result is very interesting because 1979-1982 was the only period in which the Federal Reserve told the public that it used a nonborrowed reserves as monetary instrument. This result supports Bernanke and Mihov's (1995) semi-VAR approach.

ϕ^b describes the strength of the Fed offsetting the demand for borrowed reserves shocks. This coefficient is estimated to be negative in almost all cases. The estimate of the sample period1965-1996 under the JI model is -0.787. During the period between1965 and 2009, this coefficient is estimated to -3.01. The estimate of the period1965-2007 estimate under the JI model is -0.73. This result coincides with the federal funds rate model.

α were often estimated to be a small negative number. Moreover, the estimations of β were almost always positive just as predicted.

1.7.2 First important implication

To sum up, ϕ^d is found to be greater than 1 most of the time, indicating that the nonborrowed reserve NBR model is strongly rejected. ϕ^b is always found to be negative and often close to -1, implying that federal funds rate (FFR) model is accepted. In conclusion, the federal funds rate model is strongly selected by the semi-VAR approach for all the sample periods. In other words, the Federal Reserve is still targeting the federal funds rate just as it claimed.

1.7.3 Second important implication

Comparing the estimation results of the sample period 1965-2007 (Table 1.2) with that of the sample period 1965-2009 (Table 1.3) , the coefficients significantly different from zero estimated for period 1965-2009 tend to be not significantly different from zero for period 1965-2007, which suggests the parameter changed dramatically by simply adding two more years' worth of data (2008 and 2009). This further supports that 2007 is very likely to be a break point, which reconciles the historic record.

1.8 Indications of impulse responses to monetary policy shocks

This paper ran the impulse responses to see how the macro economic variables responded to the monetary policy shocks. It updated the sample period of earlier studies to include data up to 2009. It has found that the indications of monetary policy are not always clear.[4] This finding supports the hypothesis that the incorrect nonborrowed reserve is at least one of the contributing factors to the unclear indications of monetary policy. During the recent financial crisis, much data became abnormal: total reserves were expanded by a large amount; TAF borrowing was included in the borrowed reserves but not included in the total reserves; real GDP shrunk, all of which might contribute to the unclear indications of monetary policy.

First of all, impulse responses of GDP to federal funds rate shock was tested in the federal funds rate model for the periods of 1965-1996, 1965-2007 and 1965-2009 respectively. The impulse response (Figure 1.2 and 1.3) is normal for the first two sample periods, but when adding the data of 2008 and 2009, the result (Figure 1.4) was not satisfactory.

[4] It is because that impulse response of real GDP to monetary policy shocks becomes abnormal. See both figure (1.4) and figure (1.7)

Then, the impulse response of GDP to nonborrowed reserve shocks was checked in the nonborrowed reserve model for the time frame of 1965-1996, 1965-2007 and 1965-2009 respectively, similar result was obtained (Figure 1.5, 1.6 and 1.7), the impulse response (Figure 1.5 and 1.6) is normal for the first two sample periods, but when adding the data of 2008 and 2009, the result (Figure 1.7) was not satisfactory.

What factors were there that contributed to the abnormal impulse response to policy shocks? During the recent financial crisis, much data became unusual. Among all six time series data (real GDP, GDP deflator, CPI, federal funds rate, total reserves and nonborrowed reserves) used in this paper, real GDP, federal funds rate, total reserves and nonborrowed reserves were obviously unusual during this period of time. Please see figure 1.10 through figure 1.14 for their graphs. Real GDP went down during the recent financial crisis, but it was not the first time in the U.S. history. Federal funds rate became close to zero, which was never happened before. Total reserves were largely expanded by the Federal Reserve. Moreover, nonborrowed reserves became inappropriate. All of the above factors may contribute to the abnormal impulse response to policy shocks, which implied an unclear indication of monetary policy. However, the Federal Reserve can prevent one data from being calculated wrong, that is, nonborrowed reserves data.

This paper will correct the nonborrowed reserve data. There are two ideal ways to correct the data. One way is to include TAF borrowing data in both total reserves and borrowed reserves; the other way is to exclude TAF borrowing data from both of them. I expect that the correct data will result in smoothing the impulse response or making the impulse response less volatile.

1.9 Ways to correct the wrong calculation and implications

1.9.1 Two ideal ways

There are two ideal ways to correct the nonborrowed reserve data, which was the only data that was calculated wrong among all six variables, although real GDP, federal funds rate and total reserves also became unusual during the recent financial crisis. One way is to include TAF borrowing data in both total reserves and borrowed reserves, the other way is to exclude TAF borrowing data from both of them. However, both of these methods are not practical except for gathering further information, since there is no way to know which part of TAF borrowings was included in total reserves and which part was not. For example, on November 1st, 2008, total reserve was $ 609.939 billion. Discount window borrowing was $ 305.698 billion. TAF borrowing was $ 393.088 billion. Nonborrowed reserves were $ -88.8473 billion. Clearly, not all TAF borrowing was included in total reserves; otherwise, nonborrowed reserve would be a nonnegative number. We cannot tell from these data exactly how much TAF borrowing exactly was included in total reserves.

Is it possible that none of the borrowing was included in total reserves? If this is the case, we can simply ignore the TAF borrowing data and use the old method of calculating nonborrowed reserve, that is, nonborrowed reserve is equal to total reserve minus discount window borrowing and run the impulse response. However, the Federal Reserve's data was totally out of control at that time, since even discount window borrowing exceeded total reserves in both September and October of 2008.

1.9.2 Alternative and practical ways

Not only did total borrowings (borrowing at the discount window + TAF borrowing) exceed total reserves, but even discount window borrowing exceeded total reserves in both September and October of 2008. (Please see the table 1.4 below.) The Federal Reserve should have opened a new account for the excess borrowing rather than simply including the excess borrowing in the discount window borrowing. Perhaps these data contributed to the abnormal response to policy shocks. One way to verify it is to ignore the data of September and October of 2008, since there is no way at all to fix it at this point with discount window borrowing exceeding total reserves. However, the impulse responses of GDP to shocks in both federal funds rate and nonborrowed reserve models are not satisfactory. Please see figure 1.15 and figure 1.18.

The reason for the failure of new impulse responses is when the data was ignored, even one period of data, the balance of the whole economic system was destroyed. Let's recall our model. Macroeconomic variables Y depend on current and 13 lagged values of macroeconomic variables and on 13 lagged values of policy indicators. At the same time, the policy variables depend on both current and 13 lagged values of policy variables and macroeconomic variables. In other words, all six variables have complicated relationships with each other up to 13 lagged periods. If any period data was ignored, the relationships were destroyed, which explained the unsatisfactory impulse response.

I ignored all the negative nonborrowed reserves and ran the impulse response once again. It turns out that the impulse responses of GDP to shocks in both federal funds rate and nonborrowed reserve model are unsatisfactory (Please see figure 1.16 and figure 1.19), actually even more volatile than simply ignoring two periods' data (See figure 1.17 and figure 1.20), which was just as expected. The economic system created to model the real world crashes by missing more data.

Table 1.4: Examples of discount window borrowing exceeding total reserves (Billions of dollars)

Date	Total reserves	Discount window borrowing	TAF borrowing	Total borrowing (Discount window borrowing+TAF borrowing)	Non-borrowed reserves
2008-09-01	102.767	140.291	149.814	290.105	-187.338
2008-10-01	315.498	403.541	244.778	648.319	-332.821

1.9.3 Gathering more data in future research

In future research, more data is needed because the most recent data is still abnormal. For example, the Federal Reserve just made their decision in August, 2011 to keep the federal funds rate at a low level for several years to fight the stalling economy. It seems that we have to wait for a while until the economy is back to normal as well as economic data.

1.10 Conclusions

Federal funds rate is found to be the best indicator of monetary policy, which is also claimed to be the monetary policy targeting instrument by the Federal Reserve. The semi-structural VAR model used in this paper was also applied by Bernanke and Mihov (1998), who successfully found that during 1979 to1982, the nonborrowed reserve model was strongly accepted. This period overlaps Volcker's experimental nonborrowed reserve targeting period exactly, which showed the robustness of the semi-structural VAR model.

Comparing the estimation results of the sample period 1965-2007 (Table 1.2) with that of the sample period 1965-2009 (Table 1.3) , the coefficients significantly different from zero estimated for period 1965-2009 tend to be not significantly different from zero for period 1965-2007, which suggests the parameter changed dramatically from simply adding two more years data (2008 and 2009). This further supports that 2007 is very likely to be a break point, which is consistent with the fact that the financial crisis started in the same year.

This paper tried to correct the nonborrowed reserve data, but unfortunately there is no way to fix it in an ideal way (See 1.9.1. Two ideal ways) at this point due to the lack of data. If the data can be fixed, it is expected the corrected nonborrowed reserve data will result in smoothing the impulse response or making the impulse response less volatile.

Since the two ideal ways to correct data are not at all practical, this paper tried to fix the nonborrowed reserve data when discount window borrowing exceeded total reserves. I found not only total borrowing (borrowing at the discount window + TAF borrowing) exceeded total reserves, but even discount window borrowing exceeded total reserves in both September and October of 2008. The only way I can think of is to ignore the data of September and October of 2008, since there is no way to fix it at this point with discount window borrowing exceeding total reserves. However, the impulse responses of GDP to shocks in both federal funds rate and nonborrowed reserves models are not satisfactory either. (Please see figure 1.15 and figure 1.18.)

Furthermore, I ignored all the negative nonborrowed reserve and ran the impulse response once again. It turns out that the impulse responses of GDP to shocks in both federal funds rate and nonborrowed reserve models are unsatisfactory (Please see figure 1.16 and figure 1.19.), actually even more volatile than simply ignoring two periods' data (See figure 1.17 and figure 1.20), which was just as expected. The economic system created to model the real world crashes by missing more data.

The experiments I did for fixing the nonborrowed reserve data were not successful. The reason for the failure of new impulse responses is when the data was ignored, even two periods of data, the balance of the whole economic system was destroyed. Let's recall our model. Macroeconomic variables Y depend on current and 13 lagged values of macroeconomic variables and on 13 lagged values of policy indicators. At the same time, the policy variables depend on both current and 13 lagged values of policy variables and macroeconomic variables. In other words, all six variables have complicated relationships with each other up to 13 lagged periods. If any period data was ignored, the relationships were destroyed, which explained the unsatisfactory impulse response.

The failure of these two experiments further showed the robustness of this semi-structural VAR model. In this well-structured semi-structural model: bad data (Fed's wrong nonborrowed reserves) never works as well as good data; doctored data (Experiments of ignoring two periods' data and ignoring all negative nonborrowed reserve data) never works as well as real data.

Last but not least, the abnormal impulse responses to monetary shocks showed that the Federal Reserve is at least one of the reasons for the unclear indications of monetary policy. This will become an additional support for Barnett's proposal (2012) of creating the Federal Reserve's own data bureau. During the recent financial crisis, much data went abnormal. Total reserves were expanded by a large amount (See Figure 1.14). From Jan.1, 2008, the nonborrowed reserves of U.S. banks became negative and increased to as large as 486 billion in June, 2009 (figure1.1), since part of the TAF borrowing was included in the borrowed reserves but not included in the total reserves. Real GDP shrunk (See Figure 1.10) and federal funds rate went to almost zero (See Figure 1.13), all of which might have contributed to the unclear indications of monetary policy.

A caveat to the findings is that, because of my focus on the importance of recent changes, I was unavoidably left with short sample periods. It's impossible to do semi-structural VAR on only 2008 and 2009 data (quarterly), because 13 lags were picked by both AIC and SBC. In this case, the sample period 1965 to 2007 was used to compare with the one from 1965 to 2009.

Figure 1.1: Nonborrowed Reserves (in millions of dollars)

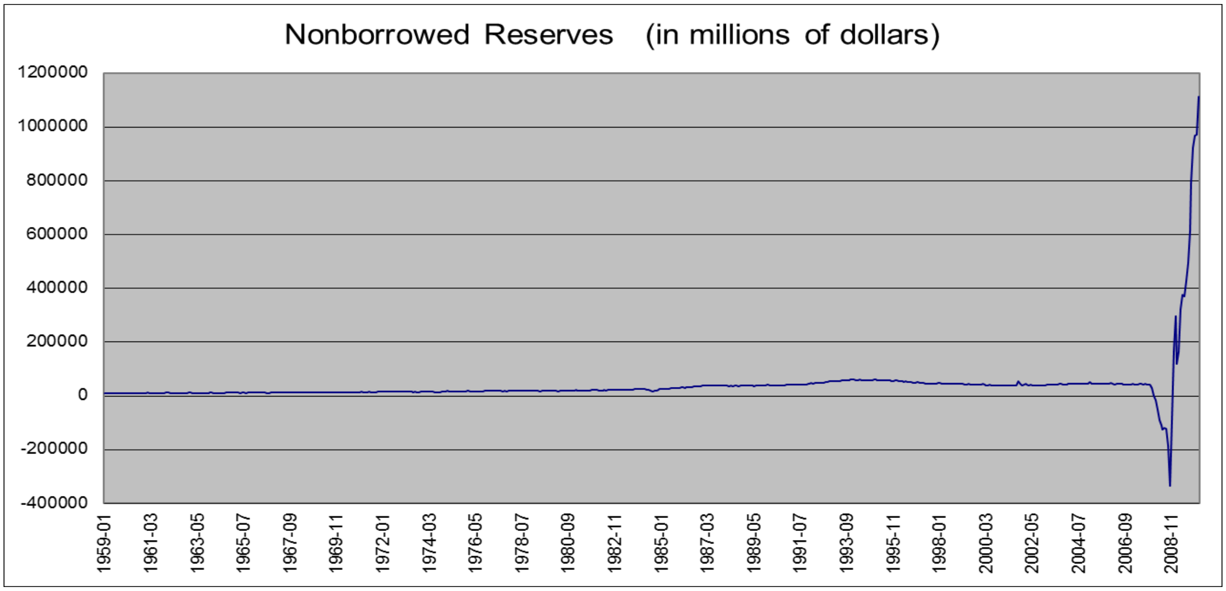


Figure 1.2 : Impulse responses of GDP to expansionary monetary policy shocks in FF model: negative shock in federal funds rates (1965-1996)

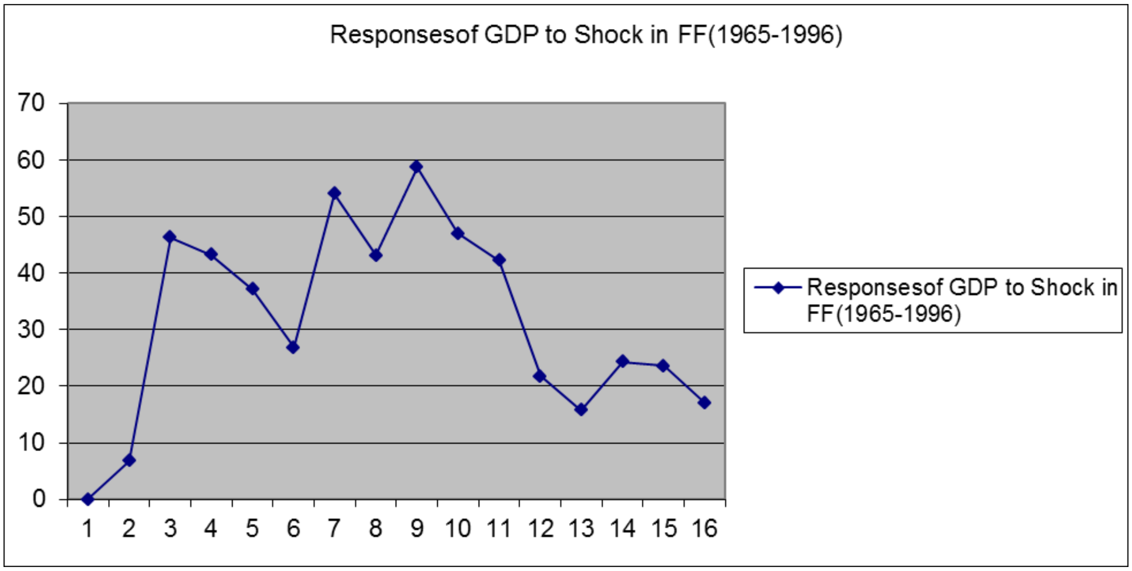


Figure 1.3: Impulse responses of GDP to expansionary monetary policy shocks in FF model: negative shock in federal funds rates (1965-2007)

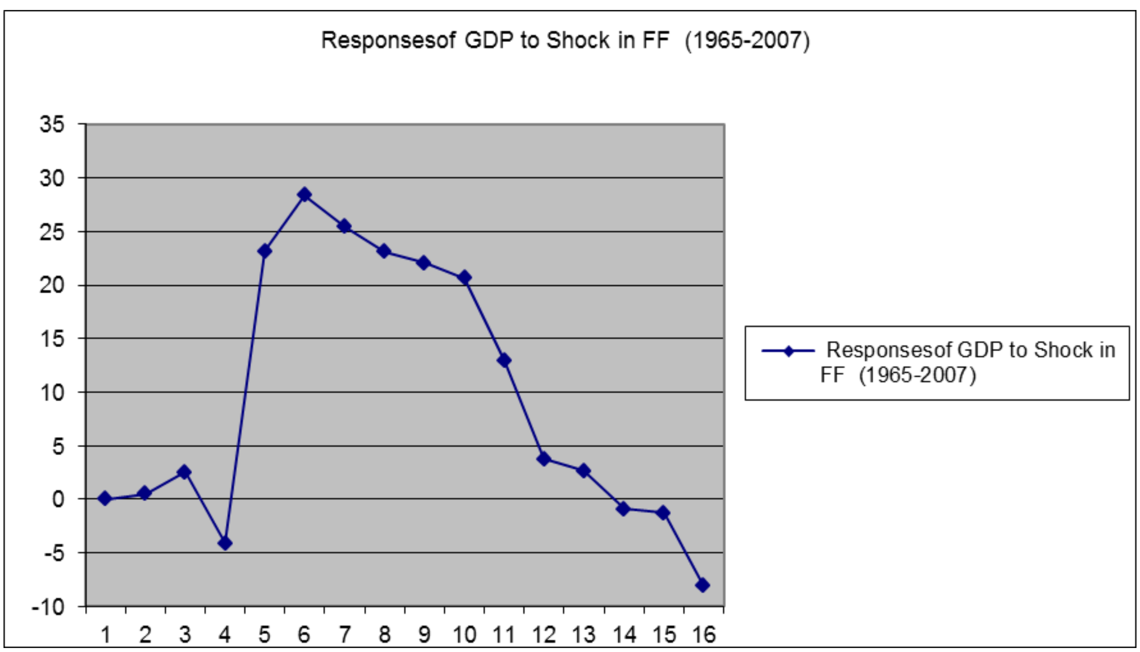


Figure 1.4: Impulse responses of GDP to expansionary monetary policy shocks in FF model: negative shock in federal funds rates (1965-2009)

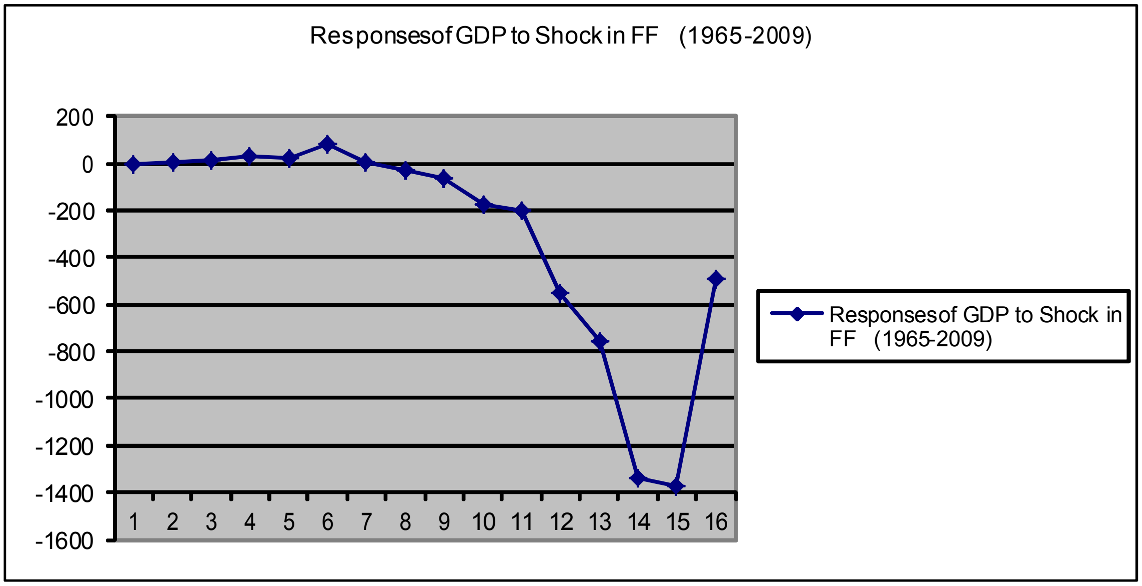


Figure 1.5: Impulse responses of GDP to shocks in NB model: positive shock in nonborrowed reserve (1965-1996)

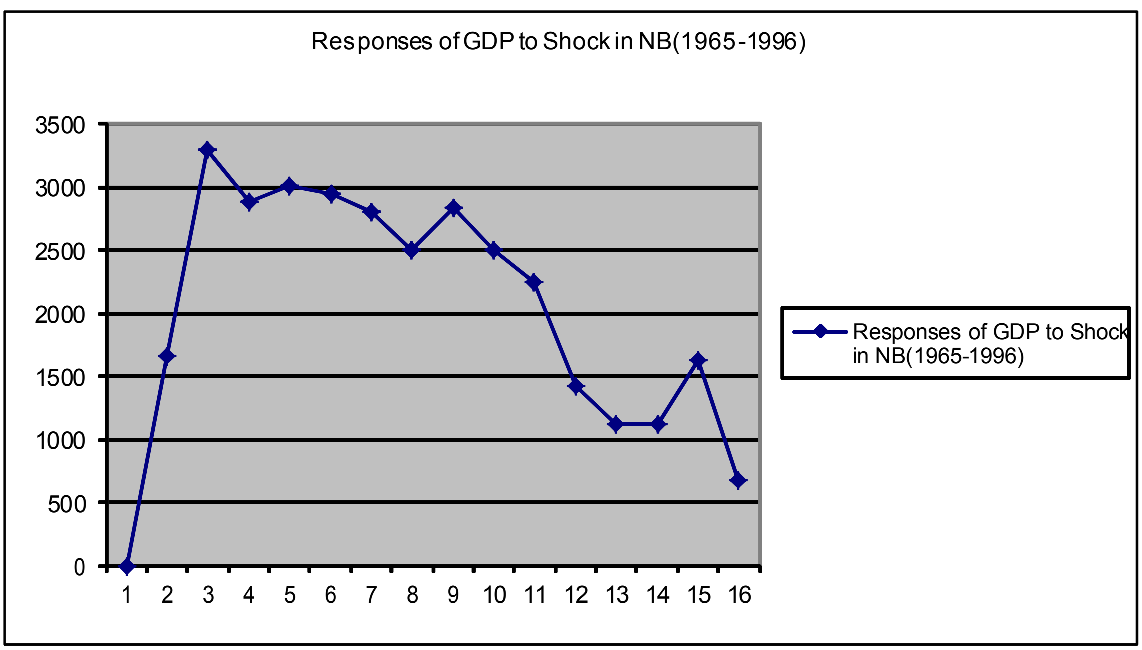


Figure 1.6: Impulse responses of GDP to shocks in NB model: positive shock in nonborrowed reserve (1965-2007)

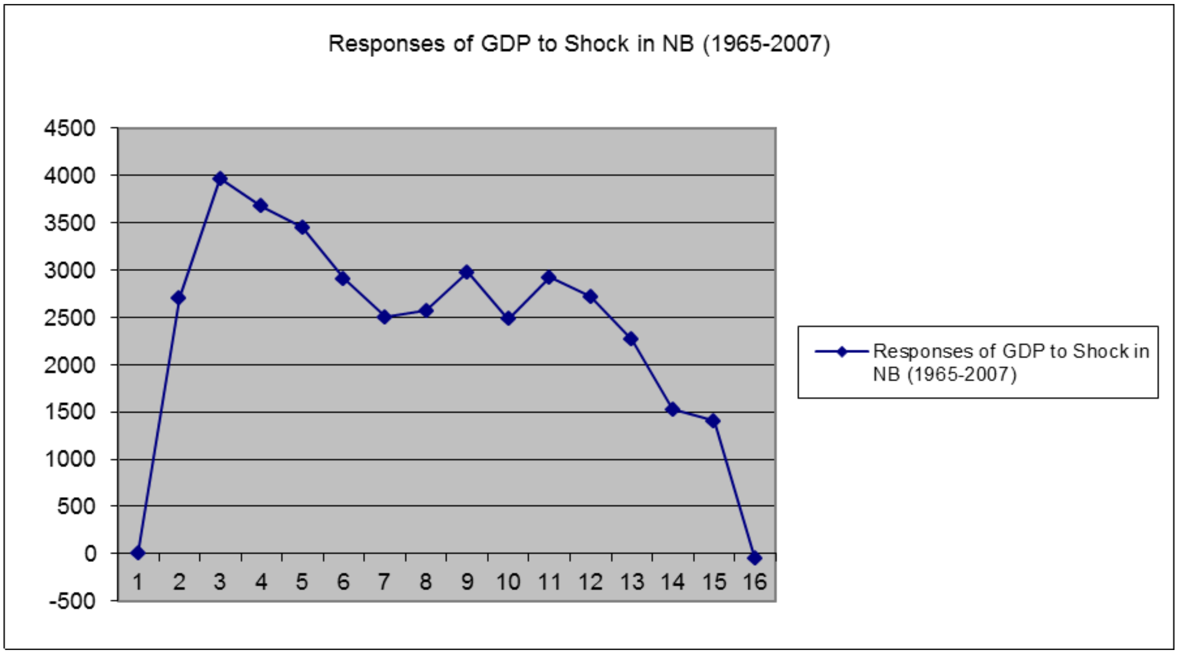


Figure 1.7: Impulse responses of GDP to shocks in NB model: positive shock in nonborrowed reserve (1965-2009)

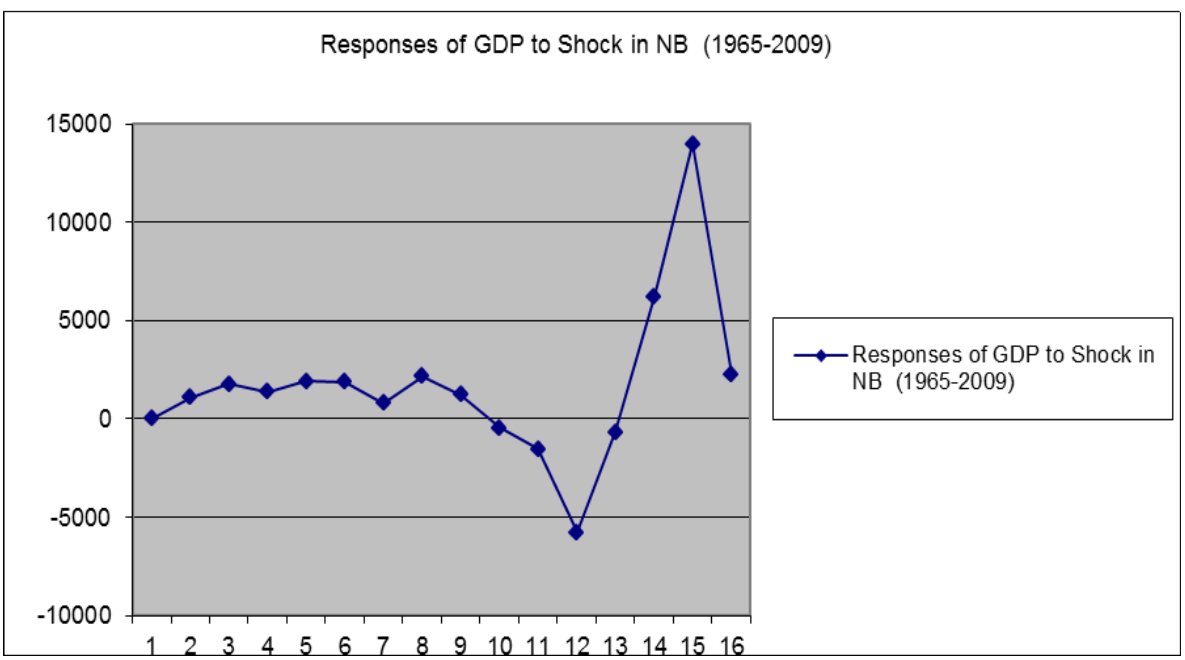


Figure 1.8: The calculation of total reserves on November 1st, 2007

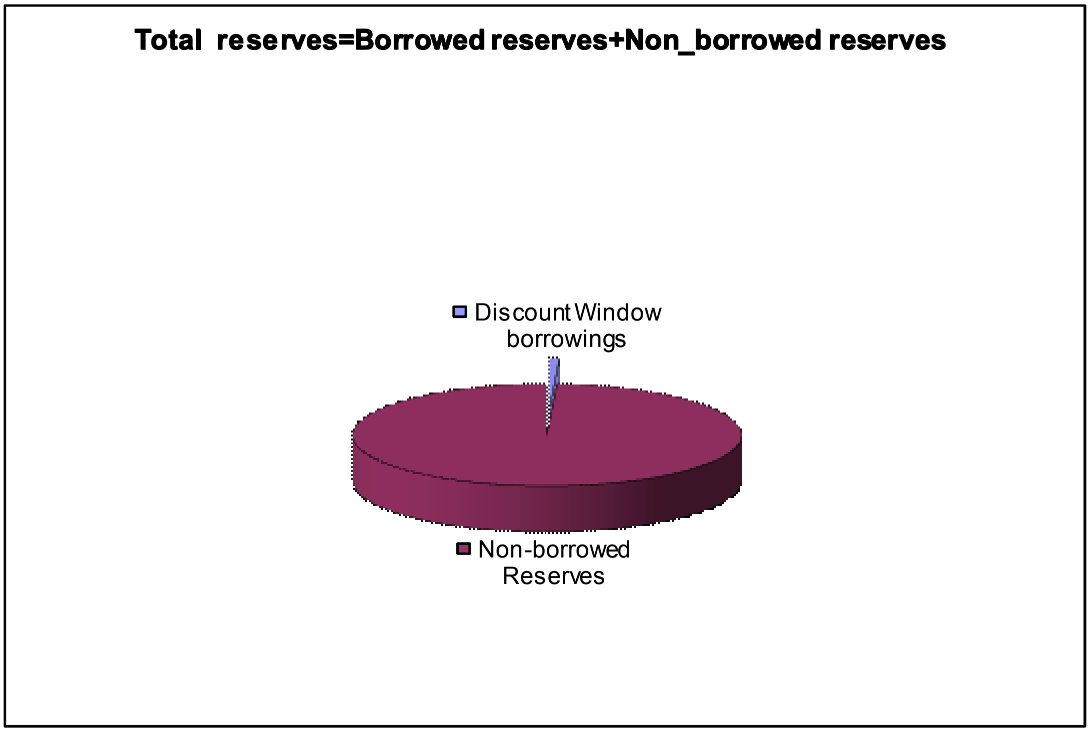
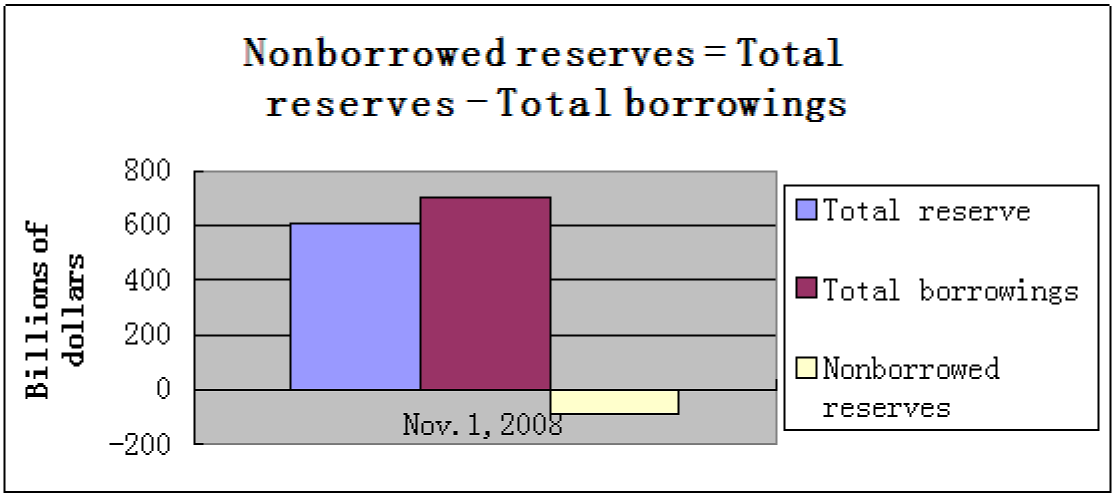


Figure 1.9: An example of recent accounting method for non-borrowed reserves[5]



[5] Total borrowings = Discount window borrowing + TAF borrowing.

Figure 1.10: GDP (1959-2009) Units: billions

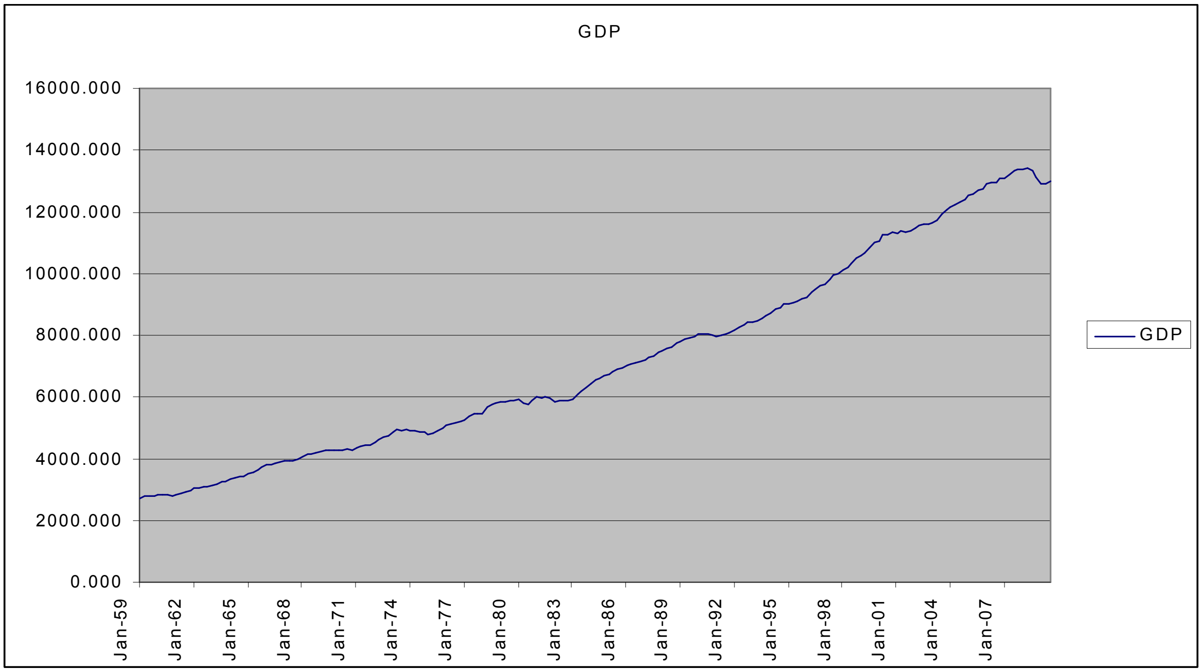


Figure 1.11: GDP deflator (1959-2009) Units: Index 2005=100

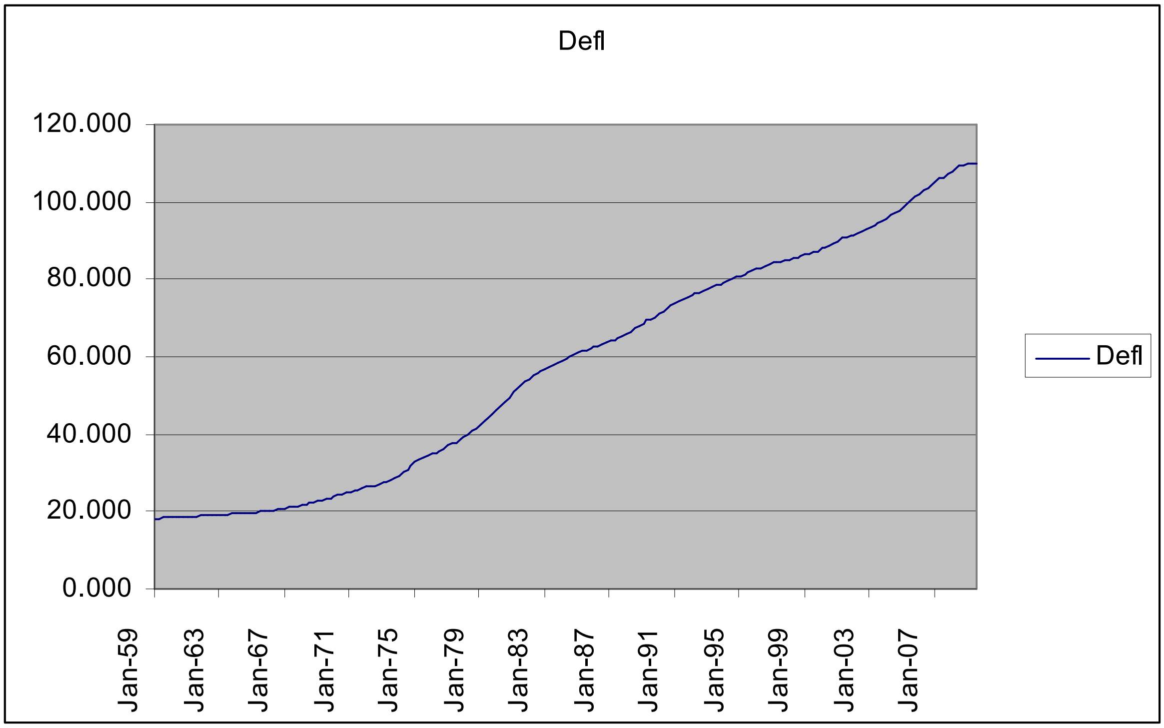


Figure 1.12: CPI (1959-2009) Units: Index 1982-84=100

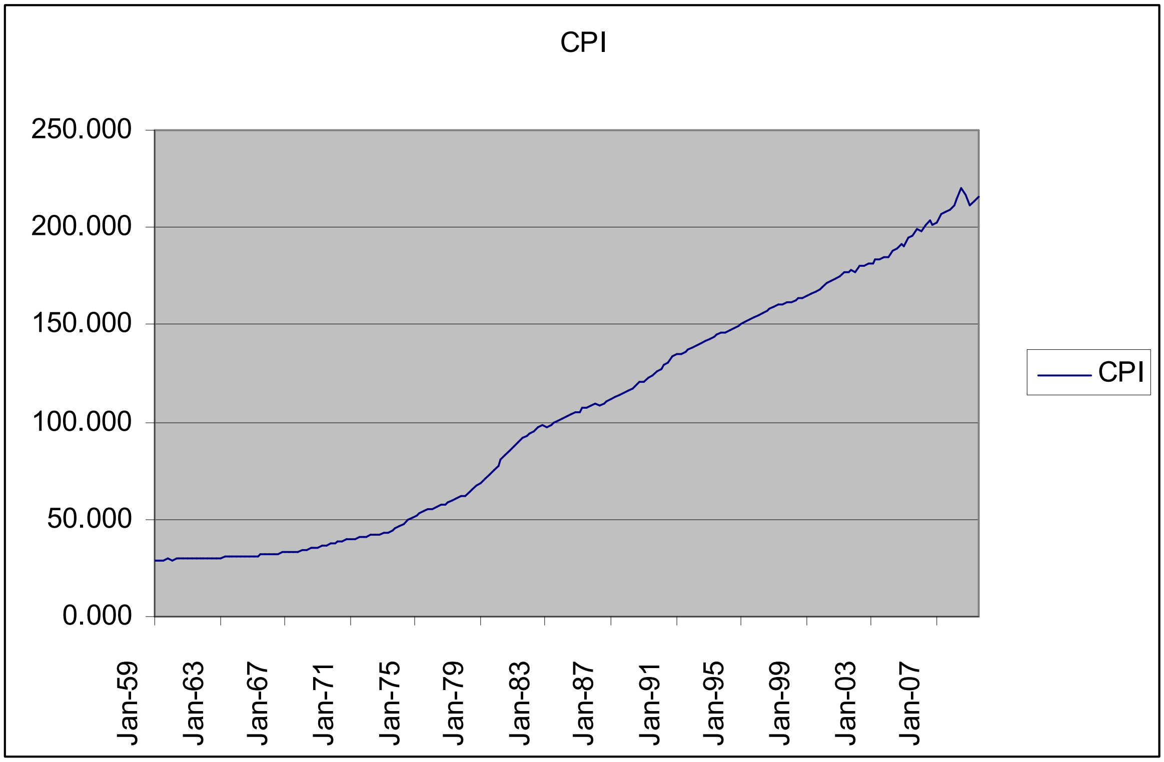


Figure 1.13: Federal funds rate (1959-2009) Units: percentage

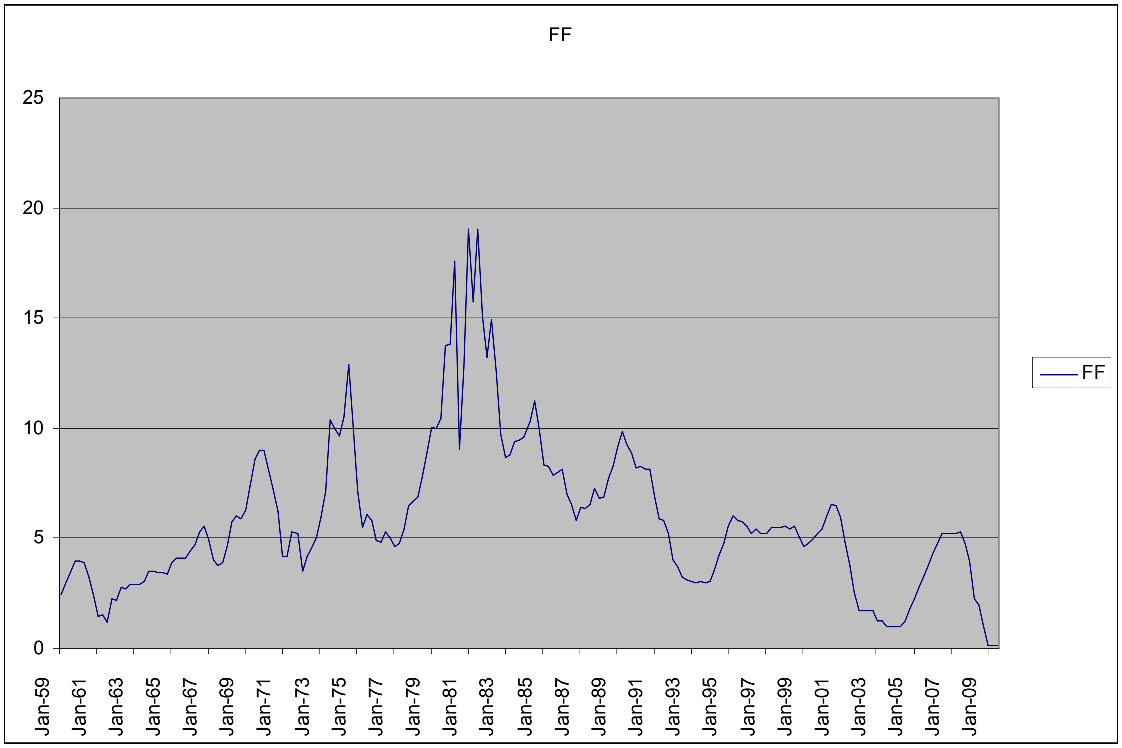


Figure 1.14: Total reserves (1959-2009) Units: billions

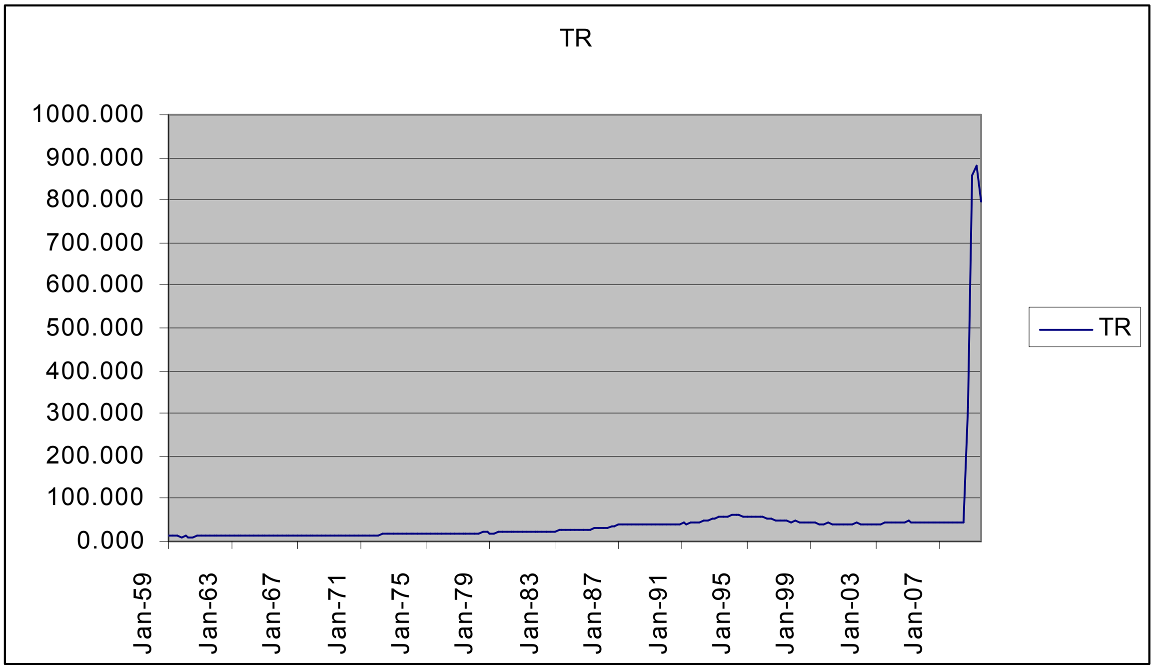


Figure 1.15: The comparison of two impulse responses in FF model: negative shock in federal funds rate (One has adjusted data.)

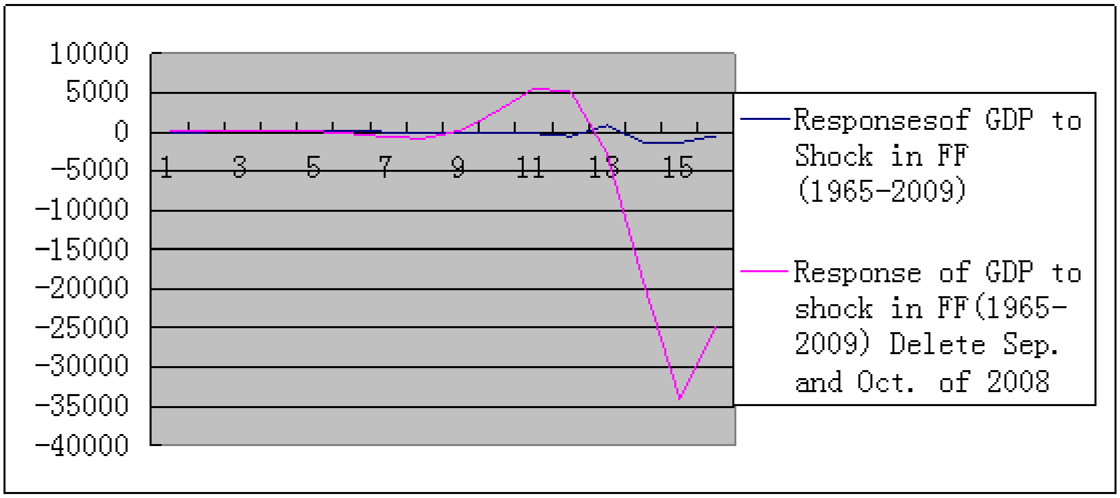


Figure 1.16: The comparison of two impulse responses in FF model: negative shock in federal funds rates (One has adjusted data.)

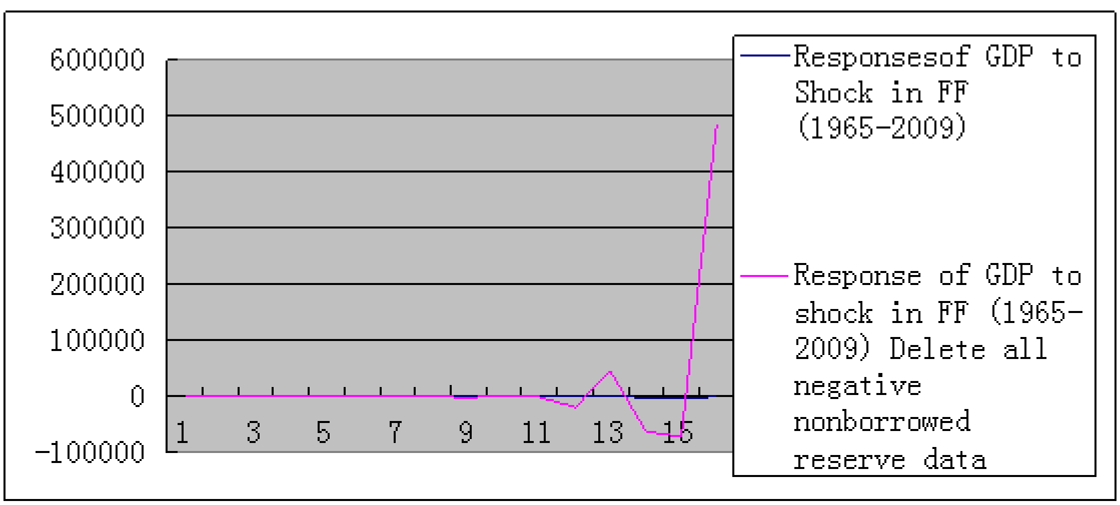


Figure 1.17: The comparison of two adjusted impulse responses in FF model: negative shock in federal funds rates

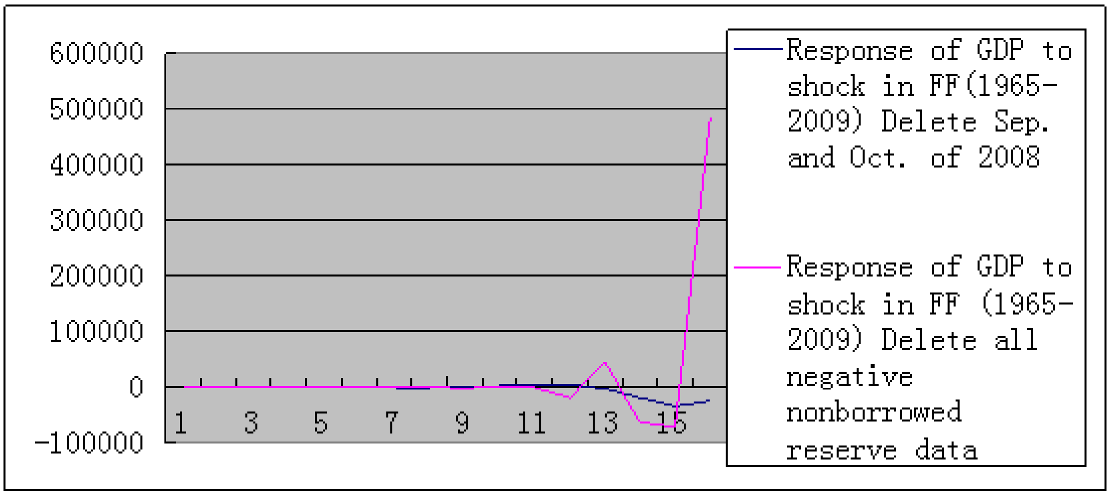


Figure 1.18: The comparison of two impulse responses in NB: positive shock in nonborrowed reserve (One has adjusted data.)

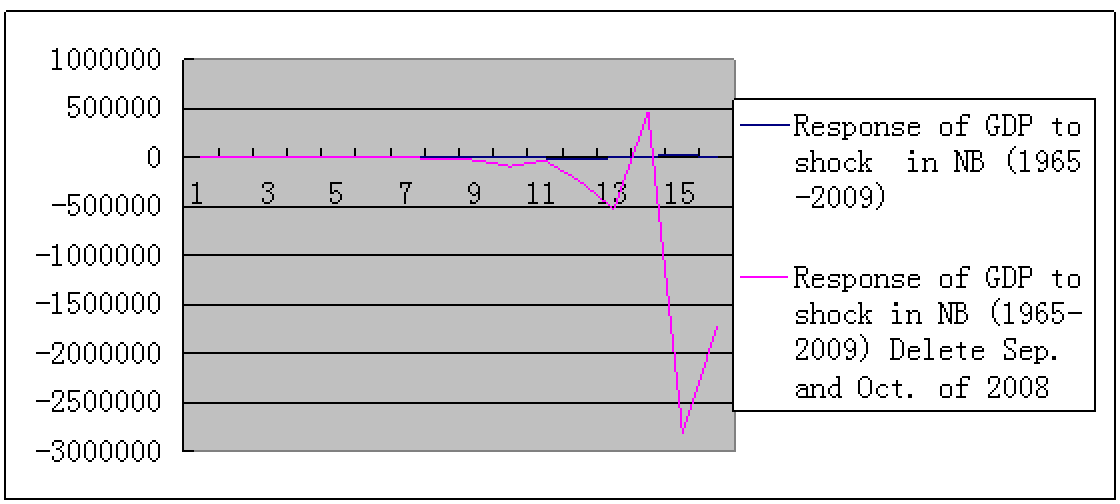


Figure 1.19: The comparison of two impulse responses in NB model: positive shock in nonborrowed reserve (One has adjusted data.)

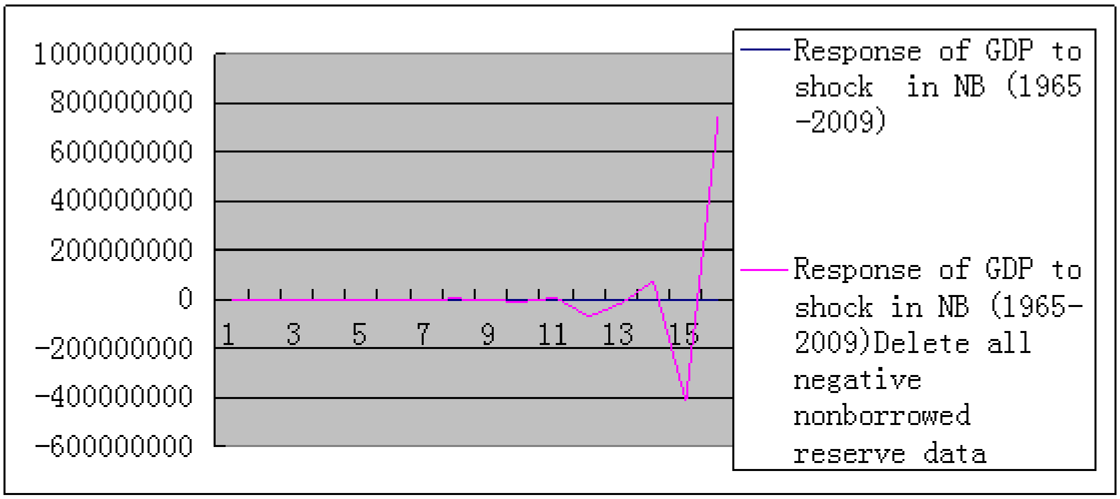
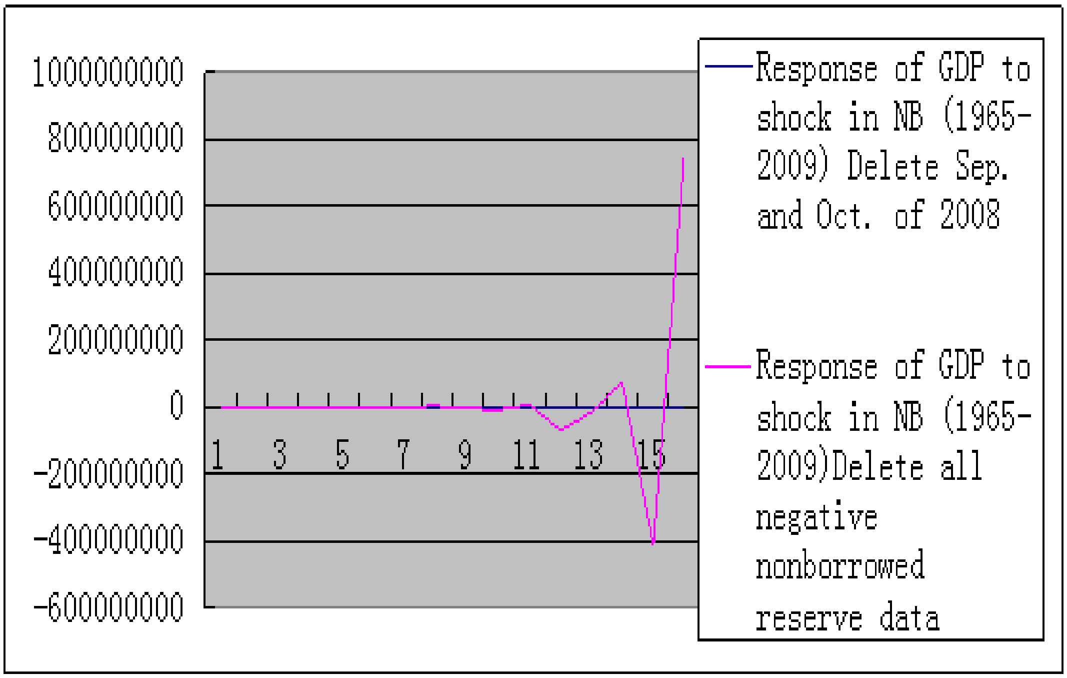


Figure 1.20: The comparison of two adjusted impulse responses in NB model: positive shock in nonborrowed reserve



2 Chapter 2: Do repurchase agreement rates contain more information for monetary policy than Treasury bill rates?

ABSTRACT

This paper aims to test whether repurchase agreement rates (repo rates) contain more information for monetary policy than Treasury bill rates during the recent two decades. First of all, this paper finds evidence that by using 3-month repo rates for forecasting federal funds rates, expectation theory performs extremely well. Previous researchers often rejected expectation theory by using Treasury bill rates. Secondly, the first result motivated my further research on comparing the abilities of repo rates with Treasury bill rates for forecasting federal funds rates. Last but not least, this article will test and compare the forecasting ability of the government, agency and mortgage repo rates and explore whether any of these three repo rates can be considered as a better riskless rate than Treasury bill rates. Although the Treasury bill rate is often applied as the riskless rate, the people in the Wall Street believed that it is biased from the riskless rate. More specifically, Treasury bill rates should be lower than riskless rates, since it has special advantages such as tax advantages.

2.1 Motivation and Literature Review

Researchers have done a considerable amount of research on the expectation ability of the Treasury bill rate. A lot of them believe that the Treasury bill rate contains information about both the economy and monetary policy. However, few of them are interested in exploring repo rates. This paper tried to fill this gap.

Why are repo rates neglected most of the time? On one hand, repo rates are not publicly available, while Treasury bill rates are easy and free to get. The only source to get repo rates data so far as I know is the Bloomberg system, which is neither free nor even cheap. This might have prevented researchers from exploring the repo rates. On the other hand, researchers are getting used to exploring Treasury bill rates and neglecting the repo rates. For example, Bernanke (1990) found the spread between the commercial paper rate and the Treasury bill rate is the best indicator for the economy among interest rates, but he never checked repo rate. Kauppi (2007) found the spread between the 6-month Treasury bill rate and federal funds rate is one of the best predictors for the future federal funds rate. However, repo rate has again been neglected.

Repurchase agreement is the first widely used money market instrument, while the Treasury bill only ranks fifth overall[6]. Why does the ranking matter? The more widely used the instrument, the more efficient its rates might be. A most efficient money market rate captures the most information from the economy and in return, might be a best indicator for the market. Furthermore, Longstaff (2000) found more evidence for this, since the expectation hypothesis is found to be unbiased by using repo rates instead of Treasury bill rates.

[6] See Kamath, Khaksari, Meier, and Winklepleck (1985).

Simon (1990) tested the predictive power of the spread between the 3-month Treasury bill rate and federal funds rate for the future federal funds rate and found the predictive power is not the same for forecasting the federal funds rate during different monetary policy regimes. The spread has most significant predictive power during the nonborrowed reserves operating regime, while it has less predictive power during the borrowed reserves regime and no predictive power during the federal funds rate targeting regime.

Longstaff (2000) has done an empirical study to support the expectations hypothesis, which was often rejected by many researchers. By testing the very short end of the term structure such as overnight, weekly, and monthly repo rates for forecasting the federal funds rate, his paper found the expectations hypothesis works very well. Furthermore, the author found the term premium in repo rates are zero except for the weekly repo rates case, which is exactly consistent with the pure form of the expectations hypothesis, which says that long-term rates can be represented as current and future short-term interest rate over the horizon of the long-term securities. Term premium is also called "liquidity premium". This premium compensates investors for the more risk of holding longer term securities, since there is higher price uncertainty existing in the longer term securities. Therefore, people prefer short term securities to long term securities and require higher return from the longer term securities.

Furthermore, Longstaff (2000) pointed out that the repo rates may be better riskless rates. He has mentioned in his paper that the Wall Street thought the Treasury bill rates were poor measures of the riskless rate, since they are not only safe but also very liquid. As a result, the Treasury bill rate should be lower than the riskless rate.

Nosal (2001) concluded that the federal funds futures rate does contain information about the future federal funds rate. However, one must make appropriate adjustments to take account of the biases and past movements of the federal funds rate. In other words, the federal funds futures rate does not provide the market with accurate estimates of the future federal funds rate at a specific point in time.

2.2 The Model

The model is based on rational expectation theory. Rational expectation theory says long-term rates can be represented as current and future short-term interest rates over the horizon of the long-term securities, plus a risk premium.

The repo rate might be a better measurement for the risk free rate than the Treasury bill rate. There are many reasons to support this point of view: First of all, repurchase agreements, especially general collateral government repurchase agreement and agency repurchase agreement are very safe money market instruments. When a company, which is considered as a seller, borrows by using a repurchase agreement, it has to provide collateral simultaneously. Later it will buy back the collaterals at a higher price. The difference between the original price and the new price can be represented as interest rates, known as repo rates. There are several different forms of collateral that the company can provide, which depend on what kind of repurchase agreement that this company plans to use. For example, there are general collateral government repurchase agreements, agency repurchase agreements and mortgage repurchase agreements. If the company decides to use a general collateral government repurchase agreement, then it will provide the lender or buyer with government securities. It is very safe for the lender. If the borrower or seller cannot pay the money back, the lender can simply sell the government securities instead. Secondly, repurchase agreements do not have the special advantages of Treasury bills, such as tax advantage. The interest earned from purchasing the Treasury bill will be exempt from state and local income taxes. That is why the Treasury bill rate is biased from the true risk free rate. More specifically, it is lower than the true risk free rate. Thirdly, the repo rate market is the most widely used, thus it is the most efficient market. To sum up, the repurchase agreement is both a safe, and efficient money market instrument without the special advantages of the Treasury bill. Therefore, the repo rate might be a better risk free rate than the Treasury bill rate.

This paper will apply the rational expectations theory by using repurchase agreements and Treasury bills as long-term securities, and the federal funds rate as the short-term rate. The purpose of this paper is not to find the best way to predict the federal funds rate, but to test whether the repo rate carry more information than the Treasury bill rate. Furthermore, this paper also will use various repo rates and Treasury bill rates as risk free rates and test whether the repo rate is a better measurement of the riskless rate.

Equation (1) represents the rational expectation theory: The 3-month repo rate is equal to the average of the current and the future federal funds rates over the 91 days to maturity, minus a risk premium and a constant. RRA_t is the 3-month repurchase agreement rate. RFF_t and $E_t(RFF_{t+i})$ are the effective federal funds rate and the expected future overnight federal funds rates, respectively, and $REURO_t$ is the 3-month eurodollar rate. The risk premium has a negative sign because federal funds are more risky than repurchase agreements as money market instruments. Furthermore, at a risky time, the market will fly to safety. In this case, the market will demand more repurchase agreements, since it is fully collaterized and thus risk free. At the same time, the market will demand less federal funds. As a result, the repo rates go up and federal funds rates go down, and the spread between them narrows. The constant is also a risk premium but at a non-time-varying term.

$$RRA_t = -\phi + (RFF_t/91) + E_t \sum_{i=1}^{90} (RFF_{t+i}/91) - \theta\ (REURO_t - RRA_t). \quad (1)$$

Equation (2) is derived by simply rearranging equation (1)

$$E_t \sum_{i=1}^{90} (RFF_{t+i}/90) - RFF_t$$
$$= (91/90)\ \phi + 91/90(RRA_t - RFF_t) + (91/90)\ \theta(REURO_t - RRA_t). \quad (2)$$

In equation (3), the average of the effective federal funds rate is expressed as the average of the expected average repurchase agreement rate plus an error:

$$\sum_{i=1}^{90} (RFF_{t+i})/90 = E_t \sum_{i=1}^{90} (RFF_{t+i}/90) + \mu_{t+i} \tag{3}$$

I derived equation (4) simply by substituting equation (3) into equation (2), where $b_0 = (91/90)\phi$, $b_1 = 91/90$, and $b_2 = (91/90)\theta$.

$$\sum_{i=1}^{90} (RFF_{t+i})/90 - RFF_t$$
$$= b_0 + b_1 (RRA_t - RFF_t) + b_2 (REURO_t - RRA_t) + \mu_{t+i}. \tag{4}$$

It is expected that estimates of b_1 should be close to 1 if the rational expectation theory performs well. b_2 should be positive since investors require more compensation to hold federal funds than repurchase agreements, because federal funds are more risky than repurchase agreements. If a company borrows money from the federal funds market, it does not need to provide any collateral. While borrowing through the repurchase agreement market, it has to provide a collateral.

If the 3-month repo rate is replaced by the overnight repo rate, then equation (4) takes the form of:

$$RFF_t = RRA_t + \phi + \theta (REURO_t - RRA_t) \tag{5}$$

Similarly, if the 3-month repo rate is replaced by 1-week, 2-week, 3-week, 1-month, and 2-month repo rates respectively, then equation (4) takes the form of (6) – (10) respectively:

$$\sum_{i=1}^{6} (RFF_{t+i}) / 6 - RFF_t = (7/6)\ \phi + (7/6)\,(RRA_t - RFF_t) + (7/6)\ \theta\,(REURO_t - RRA_t) + \mu_{t+i} \qquad (6)$$

$$\sum_{i=1}^{13} (RFF_{t+i}) / 13 - RFF_t = (14/13)\ \phi + (14/13)\,(RRA_t - RFF_t) + (14/13)\ \theta\,(REURO_t - RRA_t) + \mu_{t+i} \qquad (7)$$

$$\sum_{i=1}^{20} (RFF_{t+i}) / 20 - RFF_t = (21/20)\ \phi + (21/20)\,(RRA_t - RFF_t) + (21/20)\ \theta\,(REURO_t - RRA_t) + \mu_{t+i} \qquad (8)$$

$$\sum_{i=1}^{30} (RFF_{t+i}) / 30 - RFF_t = (31/30)\ \phi + (31/30)\,(RRA_t - RFF_t) + (31/30)\ \theta\,(REURO_t - RRA_t) + \mu_{t+i} \qquad (9)$$

$$\sum_{i=1}^{60} (RFF_{t+i}) / 60 - RFF_t = (61/60)\ \phi + (61/60)\,(RRA_t - RFF_t) + (61/60)\ \theta\,(REURO_t - RRA_t) + \mu_{t+i} \qquad (10)$$

This paper aims to compare the predictability of Treasury bill rates to that of various repo rates with different maturities, so I replace 3-month repo rates with 3-month Treasury bill rates in equation (4):

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t = b_0 + b_1\,(TB_t - RFF_t) + b_2\,(REURO_t - TB_t) + \mu_{t+i}\,. \qquad (11)$$

2.3 Data

The data of my study consists of daily observations of the 1-month and 3-month general collateral government repo rates, agency repo rates and mortgage repo rates. The period covered by the study is from May 21, 1991 to February 10, 2011. Repo rates data is neither publicly available nor free. The only source that provides this data is the Bloomberg system, so far as I know.

The federal funds rate, 1-month Treasury bill rate, 3-month Treasury bill rate, 1-month eurodollar rate and 3-month eurodollar rate are from the Federal Reserve database.

Government repo, agency repo, mortgage repo, federal funds, Treasury bill and eurodollar rates are denoted as $RRAG_t$, $RRAA_t$, $RRAM_t$, RFF_t, TB_t and $REURO_t$, respectively.

The Treasury bill rate has its data limitation in maturity. It does not have shorter-term maturity, which makes it of limited use to test the expectations hypothesis.

Because of heteroskedasticity, this paper will use General Least Squares (GLS) regression.

This paper will run the GLS on the following equations:

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t = b_0 + b_1 (TB_t - RFF_t) + b_2 (REURO_t - TB_t) + \mu_{t+i}. \tag{12}$$

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t = b_0 + b_1 (RRAM_t - RFF_t) + b_2 (REURO_t - RRAM_t) + \mu_{t+i}. \tag{13}$$

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t = b_0 + b_1 (RRAA_t - RFF_t) + b_2 (REURO_t - RRAA_t) + \mu_{t+i}. \tag{14}$$

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t$$

$$= b_0 + b_1 (RRAG_t - RFF_t) + b_2 (REURO_t - RRAG_t) + \mu_{t+i} .$$

(15)

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t$$
$$= b_0 + b_1 (RRAM_t - RFF_t) + b_2 (REURO_t - RRAG_t) + \mu_{t+i} .$$

(16)

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t$$
$$= b_0 + b_1 (RRAA_t - RFF_t) + b_2 (REURO_t - RRAG_t) + \mu_{t+i} .$$

(17)

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t$$
$$= b_0 + b_1 (RRAG_t - RFF_t) + b_2 (REURO_t - TB_t) + \mu_{t+i} . \quad (18)$$

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t$$
$$= b_0 + b_1 (RRAM_t - RFF_t) + b_2 (REURO_t - TB_t) + \mu_{t+i} . \quad (19)$$

$$\sum_{i=1}^{90} (RFF_{t+i}) / 90 - RFF_t$$
$$= b_0 + b_1 (RRAA_t - RFF_t) + b_2 (REURO_t - TB_t) + \mu_{t+i} . \quad (20)$$

In the process of collecting repo rate data, I found that with the same maturity date, the mortgage repo rate is higher than the government repo rate, followed by the agency repo rate. The agency repo rate is the lowest, since it is the safest one. (Mortgage repo rate > Government repo rate > Agency repo rate)

2.4 Estimation Results

This section showed estimation results of repo rates and Treasury bill rates with different maturities at various sample periods. The main purpose of this part is to see how well the expectation theory works by applying different experiments. The most important finding of this section is that expectation theory works extremely well by using 3-month repo rates for forecasting federal funds rates rather than Treasury bill rates during the years 2001 through 2006.

2.4.1 First Result (1991-2011) -- expectation performances of 3-month repo rates and 3-month Treasury bill rates

Table 2.1: Summary of expectation performance of 3-month repo rates and 3-month Treasury bill rates (1991-2011)

	b_1 (use TB, RRAA, RRAM, RRAG as risk free rate repectively)	b_1 (use RRAG as risk free rate)	b_1 (use TB as risk free rate)
TB	.855132**	___	.855132**
RRAA	.4872037**	.3841263*	.3033689 **
RRAM	.3878825**	.3735851**	.3065694**
RRAG	.3844628**	.3844628**	.2939622**

** = statistical significance ($p < 0.05$)

Firstly, this paper tests the forecasting ability of the 3-month Treasury bill rate, mortgage repo rate, agency repo rate, and government repo rate by using their respective rates as risk free rates, and finds that 3-month repo rates are less predictive than 3-month Treasury bill rates. Please see tables 2.5 through 2.8, which correspond to equations 12 through 15. This result contradicts Longstaff's (2000) finding. Furthermore, the agency repo rate has more predictive power for the federal funds rate than both the government repo rate and mortgage repo rate.

Secondly, by using the government repo rate as riskless rate to test the forecasting ability of mortgage repo, agency repo, and government repo rates, the 3-month repo rate is less predictive than the 3-month Treasury bill rate. Please see table 2.5 and tables 2.8 through 2.10, which correspond to equation 12 and equations 15 through 17. Moreover, the government repo rate and mortgage repo rate have slightly better predictive power than the agency repo rate.

Thirdly, by using the 3-month Treasury bill rate as riskless rate to test the forecasting ability of Treasury bill, mortgage repo, agency repo, and government repo rates, the 3-month repo rate is less predictive than the 3-month Treasury bill rate. Please see table 2.5 and tables 2.11 through 2.13, corresponding to equation 12 and equations 18 through 20. The mortgage repo rate has slightly better predictive power than the other two rates.

Above all, the 3-month repo rates contain less predictive power for forecasting the federal funds rate than the 3-month Treasury bill rate. This result contradicts Longstaff's (2000) finding. Mortgage repo, agency repo and government repo rates have the most predictive power when using their respective rates as risk free rates. (For example, the mortgage repo rate has the most predictive power when using mortgage repo rates rather than other repo rates as riskless rates.) Under this circumstance, the agency repo rate has much more predictive power for the federal funds rate than both the government repo rate and mortgage repo rate.

2.4.2 Second Result (2001-2011) – expectation performances of 1-month repo rates and 1-month Treasury bill rates

This paper tried shorter-term, 1-month repo rates and applied the expectation theory again. Since the earliest 1-month Treasury bill rate data published on the Federal Reserve website is July, 31, 2001, this paper will cover the period from then until 2011.

If the 3-month repo rate " RRA_t" is replaced by the 1-month repo rate " $RRA1_t$", and the 3-month euro dollar rate " $REURO_t$" is replaced by the 1-month euro dollar rate " $REURO1_t$", then equation (1) changes into:

$$RRA1_t = -\phi + (RFF_t/31) + E_t\sum_{i=1}^{30} (RFF_{t+i}/31) - \theta (REURO1_t - RRA1_t). \quad (1)'$$

Equation (2)' is derived by simply rearranging equation (1)'

$$E_t\sum_{i=1}^{30} (RFF_{t+i}/30) - RFF_t = (31/30)\Phi + 31/30(RRA1_t - RFF_t) + (31/30)\Theta(RRA1_t) \quad (2)'$$

In equation (3)', the average federal funds rate is equal to the average of the expected average repurchase agreement rate plus an error:

$$\sum_{i=1}^{30} (RFF_{t+i})/30 = E_t\sum_{i=1}^{30} (RFF_{t+i}/30) + \mu_{t+i} \quad (3)'$$

I derived equation (4)' simply by substituting equation (3)' into equation (2)', where b_0= (31/30) ϕ, b_1 =31/30, and b_2= (31/30) θ.

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (RRA1_t - RFF_t) + b_2 (REURO1_t - RRA1_t) + \mu_{t+i}. \quad (4)'$$

This paper will further run GLS on the following equations:

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (TB1_t - RFF_t) + b_2 (REURO1_t - TB1_t) + \mu_{t+i} . \qquad (12)'$$

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (RRAM1_t - RFF_t) + b_2 (REURO1_t - RRAM1_t) + \mu_{t+i} . \qquad (13)'$$

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (RRAA1_t - RFF_t) + b_2 (REURO1_t - RRAA1_t) + \mu_{t+i} . \qquad (14)'$$

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (RRAG1_t - RFF_t) + b_2 (REURO1_t - RRAG1_t) + \mu_{t+i} . \qquad (15)'$$

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (RRAM1_t - RFF_t) + b_2 (REURO1_t - RRAG1_t) + \mu_{t+i} . \qquad (16)'$$

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$
$$= b_0 + b_1 (RRAA1_t - RFF_t) + b_2 (REURO1_t - RRAG1_t) + \mu_{t+i} . \qquad (17)'$$

$$\sum_{i=1}^{30} (RFF_{t+i})/30 - RFF_t$$

$$= b_0 + b_1 (RRAG1_t - RFF_t) + b_2 (REURO1_t - TB1_t) + \mu_{t+i} . \qquad (18)'$$

$$\sum_{i=1}^{30} (RFF_{t+i}) / 30 - RFF_t$$
$$= b_0 + b_1 (RRAM1_t - RFF_t) + b_2 (REURO1_t - TB1_t) + \mu_{t+i} . \qquad (19)'$$

$$\sum_{i=1}^{30} (RFF_{t+i}) / 30 - RFF_t$$
$$= b_0 + b_1 (RRAA1_t - RFF_t) + b_2 (REURO1_t - TB1_t) + \mu_{t+i} . \qquad (20)'$$

Table 2.2: Summary of expectation performances of 1-month repo rates and 1-month Treasury bill rates (2001-2011)

	b_1 (use TB, RRAA, RRAM, RRAG as risk free rate repectively)	b_1 (use RRAG as risk free rate)	b_1 (use TB as risk free rate)
TB	.2257429**	___	.2257429**
RRAA	.1906754**	.171021**	.1077169**
RRAM	.1953029**	.1873153**	.1148022**
RRAG	.1953356**	.1953356**	.1163421**

** = statistical significance ($p < 0.05$)

First of all, this paper tests the forecasting ability of the 1-month Treasury bill rate, mortgage repo rate, agency repo rate, and government repo rate by using their respective rates as risk free rates, and finds that the 1-month repo rate is less predictive than the 1-

month Treasury bill rate. Please see tables 2.14 through 2.17, which correspond to equations (12)' through (15)'. This result contradicts Longstaff's (2000) finding. Furthermore, the government repo rate and mortgage repo rate have slightly more predictive power for the federal funds rate than the agency repo rate.

Next, by using the 1-month government repo rate as the risk free rate to test the forecasting ability of the 1-month mortgage repo, agency repo, and government repo rates, this paper did not find evidence that the 1-month repo rate is more predictive than the 1-month Treasury bill rate. Please see table 2.14 and tables 2.17 through 2.19, which correspond to equation (12)' and equations (15)' through (17)'. Moreover, the mortgage repo rate has slightly better predictive power than both the government repo rate and agency repo rate.

Finally, by using the 1-month Treasury bill rate as riskless rate to test the forecasting ability of 1-month Treasury bill, mortgage repo, agency repo, and government repo rates, this paper found evidence that the 1-month repo rate is less predictive than the 1- month Treasury bill rate. Please see table 2.14 and tables 2.20 through 2.22, corresponding to equation (12)' and equations (18)' through (20)'. The mortgage repo rate has slightly better predictive power than the other two rates.

To sum up, the 1-month repo rate contains less predictive power for forecasting the federal funds rate than the 1-month Treasury bill rate during the years 2001 through 2010. This result contradicts Longstaff's (2000) finding. 1-month mortgage repo, agency repo and government repo rates have the most predictive power when using their respective rates as risk free rates. (For instance, 1-month agency repo rate has more predictive power when using the agency repo rate as the risk free rate.) Under this circumstance, the government repo rate and mortgage repo rate have slightly more predictive power for the federal funds rate than the agency repo rate.

2.4.3 Third Result (2001-2006) -- expectation performances of 1-month repo rates and 1-month Treasury bill rates

To eliminate the influence of the abnormal data on the expectation performances during the recent sub-prime mortgage crisis, this paper tried the 1-month repo rate again for the period from July, 31, 2001 to December, 29, 2006, since the first chapter concluded that 2007 is a breaking point. The federal funds rate data became abnormal from this point, it will make the expectation performances of both repo rates and Treasury bill rates biased.

Table 2.3: Summary of expectation performances of 1-month repo rates and 1-month Treasury bill rates (2001-2006)

	b_1 (use TB, RRAA, RRAM, RRAG as risk free rate repectively)	b_1 (use RRAG as risk free rate)	b_1 (use TB as risk free rate)
TB	.5078731**	___	.5078731**
RRAA	.4171425**	.2735823**	.1215584**
RRAM	.4148832**	.2948247**	.1266883**
RRAG	.4047939**	.4047939**	.1478132**

** = statistical significance ($p < 0.05$)

Firstly, this paper tests the forecasting ability of the Treasury bill rate, and three types of repo rates by using their respective rates as risk free rates and finds the 1-month repo rate is less predictive than the 1-month Treasury bill rate. Please see tables 2.23

through 2.26, which correspond to equations (12)' through (15)'. This result contradicts Longstaff's (2000) finding. Furthermore, the agency repo rate and mortgage repo rate have slightly more predictive power for the federal funds rate than the government repo rate. (The agency repo rate has the best predictive power, the mortgage repo rate has the second best, followed by the government repo rate.)

Secondly, by using the 1-month government repo rate as the risk free rate to test the forecasting ability of the 1-month mortgage repo, agency repo, and government repo rates, this paper found 1-month repo rate is less predictive than 1-month Treasury bill rate. Please see table 2.23 and tables 2.26 through 2.28, which correspond to equation (12)' and equations (15)' through (17)'. Moreover, the government repo rate has better predictive power than both the mortgage repo rate and agency repo rate.

Finally, by using the 1-month Treasury bill rate as riskless rate to test the forecasting ability of 1-month Treasury bill, mortgage repo, agency repo, and government repo rates, this paper found that the 1-month repo rate is less predictive than the 1- month Treasury bill rate. Please see table 2.23 and tables 2.29 through 2.31, corresponding to equation (12)' and equations (18)' through (20)'. The government repo rate has slightly better predictive power than the other two rates.

To sum up, the 1-month repo rate contains less predictive power for forecasting the federal funds rate than the 1-month Treasury bill rate during the years 2001 through 2006. This result contradicts Longstaff's (2000) finding. However, after ignoring the recent abnormal data of the federal funds rate, expectation performances of 1-month government repo, agency repo, and mortgage repo rates are better. 1-month mortgage repo, agency repo and government repo rates have the most predictive power when using their respective rates as risk free rates. (For instance, the agency repo rate has more predictive power when using the agency repo rate as riskless rate.) Under this circumstance, the agency repo rate and mortgage repo rate have slightly more predictive power for the federal funds rate than the government repo rate.

2.4.4 Fourth Result (2001-2006) -- expectation performances of 3-month repo rates and 3-month Treasury bill rates

From the previous result, we can see that expectation performance of the 1-month repo rate improved when ignoring abnormal data of the federal funds rate. Then the next question is whether the expectation performance of 3-month repo rate will also improve after ignoring those data. This paper tested predictive power of 3-month repo rates from July, 31, 2001 to December, 29, 2006, the same period covered in the previous section, so that we can compare which term rates have better predictive power.

Table 2.4: Summary of expectation performances of 3-month repo rates and 3-month Treasury bill rates (2001-2006)

	b_1 (use TB, RRAA, RRAM, RRAG as risk free rate repectively)	b_1 (use RRAG as risk free rate)	b_1 (use TB as risk free rate)
TB	1.505271**	___	1.505271**
RRAA	.9844044**	.7713213**	.3009399**
RRAM	.9785054**	.7625493**	.3032037**
RRAG	.9734084**	.9734084**	.3241937**

** = statistical significance ($p < 0.05$)

First of all, this paper tests the forecasting ability of the 3-month Treasury bill rate, mortgage repo rate, agency repo rate, and government repo rate by using their respective rates as risk free rates, and finds that 3-month repo rates are much more predictive than 3-month Treasury bill rates. Because the first coefficient on equations 13 through 15 is close to 1, which means the predictive power of repo rates is extremely strong. Please see tables 2.32 through 2.35, which correspond to equations (12) through (15). This result is consistent with Longstaff's (2000) finding. Furthermore, the agency repo rate has the best predictive power, the mortgage repo rate has the second best, followed by the government repo rate.

Next, by using the 3-month government repo rate as the risk free rate to test the forecasting ability of the 3-month mortgage repo, agency repo, and government repo rates, this paper found 3-month repo rates are more predictive than 3-month Treasury bill rates, since the first coefficients are more closer to 1 in equations 15 to 17 than in equation 12. Please see table 2.32 and tables 2.35 through 2.37, which correspond to equation (12) and equations (15) through (17). Moreover, the government repo rate has better predictive power than both the mortgage repo rate and the agency repo rate.

Finally, by using the 3-month Treasury bill rate as riskless rate to test the forecasting ability of 3-month Treasury bill, mortgage repo, agency repo, and government repo rates, this paper found both 3-month repo and 3-month Treasury bill rates have poor predictive power. Please see table 2.32 and tables 2.38 through 2.40, corresponding to equation (12) and equations (18) through (20). The government repo rate has slightly better predictive power than the other two rates.

To sum up, 3-month agency repo, government repo and mortgage repo rates contain better predictive power for forecasting federal funds rates than 3-month Treasury bill rates during the years 2001 through 2006. In fact, repo rates can predict federal funds rate extremely well. This result is consistent with Longstaff's (2000) finding. Longstaff (2000) found evidence to support pure expectation hypothesis by using shorter term repo rate. In other words, long term repo rates can forecast the average future overnight repo rates very well. After ignoring the recent abnormal data, expectation performances of 3-month repo rates are much better. 3-month mortgage repo, agency repo and government repo rates have the most predictive power when using their respective rates as risk free rates. (For instance, the agency repo rate has the most predictive power when using the agency repo rate as riskless rate.) Under this circumstance, the agency repo rate has the best predictive power, the mortgage repo rate has the second best, followed by the government repo rate.

2.5 Expected daily and future average 90 day federal funds rates (2001-2006)

From the previous section, this paper found evidence that by using 3-month repo rates for forecasting federal funds rates, expectation theory works extremely well. This result motivated my further research on forecasting federal funds rates by using 3-month repo rates. In this section, both daily federal funds rates and average 90 day federal funds rates will be estimated from agency repo rates, government repo rates, mortgage repo rates and Treasury bill rates. The sample period is from years 2001 through 2006.

By rearranging equation (4), we can get equation (21),

$$\sum_{i=1}^{90} (RFF_{t+i})/90 = b_0 + b_1(RRA_t - RFF_t) + RFF_t + b_2(REURO_t - RRA_t) + \mu_{t+i} \quad (21)$$

If we want to use 3-month repo rates or Treasury bill rates to forecast future average 90 day federal funds rates, then equation (21) becomes equation (22),

$$E\sum_{i=1}^{90} (RFF_{t+i})/90 = b_0 + b_1(RRA_t - RFF_t) + RFF_t + b_2(REURO_t - RRA_t) \quad (22)$$

We can further get expected daily federal funds rates from equation (23),

$$E(RFF_{t+90}) = E\sum_{i=1}^{90} (RFF_{t+i}) - \sum_{i=1}^{89} (RFF_{t+i})$$
$$= 90*[b_0 + b_1(RRA_t - RFF_t) + RFF_t + b_2(REURO_t - RRA_t)] - \sum_{i=1}^{89} (RFF_{t+i}) \quad (23)$$

The idea of getting expected daily federal funds rates come from the following:

First of all, this paper will show that if one knows the first three days' numbers, then it can forecast the next three days' numbers.

By assumption, if one knows any day's number, then it can forecast the average of the future 3 days' numbers. In other words, any day's number is equal to the average of the next 3 days numbers. Letters "a" through "f" denote numbers.

Table 2. 55

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
a	b	c	d	e	f	g	h

In day one, we know that "a" is equal to 3. Therefore,

(b+c+d)/3=3 (24)

In day two, we know that "b" is equal to 4. Therefore,

(c+d+e)/3=4 (25)

In day three, we know that "c" is equal to 6. Therefore,

(d+e+f)/3=6 (26)

From Equations (24) through (26),

We can get d = -1, e = 7, f = 12.

Secondly, by similarity, we can show that if one knows the first four days' numbers, then it can be forecast the next four days' numbers. By assumption, if one knows any day's number, then it can be forecast the average of the future 4 days' numbers.

In day one, we know that "a" is equal to 3. Therefore,

(b+c+d+e)/4=3 (27)

In day two, we know that "b" is equal to 4. Therefore,

(c+d+e+f)/4=4 (28)

In day three, we know that "c" is equal to 6. Therefore,

(d+e+f+g)/4=6 (29)

In day four, we know that "d" is equal to 8. Therefore,

(e+f+g+h)/4=8 (30)

From Equations (27) through (30),

We can get e = -2 , f = 4 , g = 14 , h = 16.

Lastly, we can show that if one knows the first 90 days' numbers, then it can be forecast the next 90 days' numbers. Every time when one knows one more day's number, it will help to forecast one more day's number further. This paper will apply the hypothesis that if we have daily 3-month repo rates for 90 days, then we can forecast the daily future federal funds rates for the next 90 days for the sample period from 2001 to 2006. Then I will compare the forecasting overnight repo rates with the actual repo rates.

2.5.1 Expected federal funds rates from agency repo rates (2001-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month agency repo rates.The estimated coefficients are b_0 = -0.1271211, b_1=0.9844044, b_2=0.7834065. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the agency repo rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). Finally, after getting both estimated average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.1 through 2.3)

Figure 2. 1 Actual and expected average 90 day federal funds rates from 3-month agency repo rates (2001-2006)

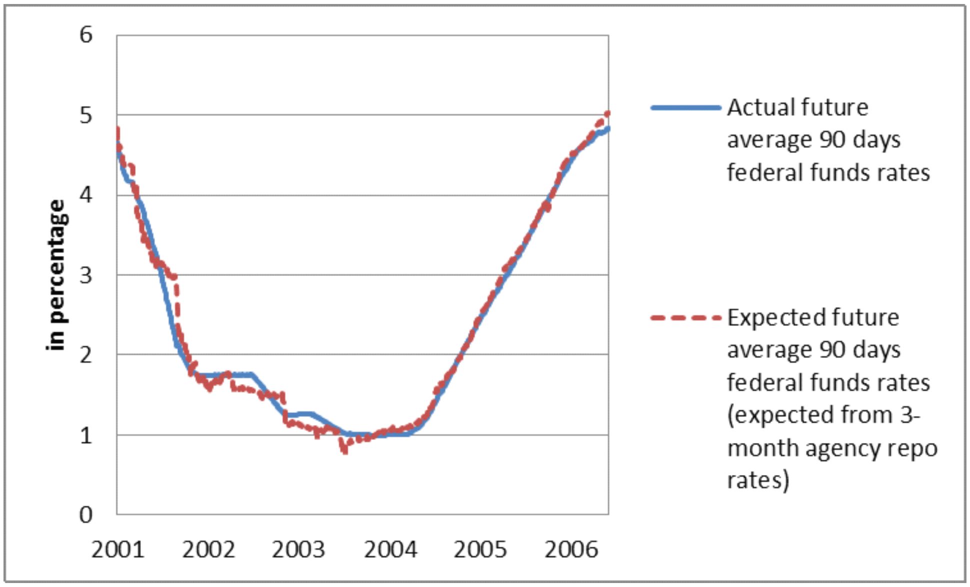


Figure 2. 2 Actual and expected daily federal funds rates from 3-month agency repo rates (2001-2006)

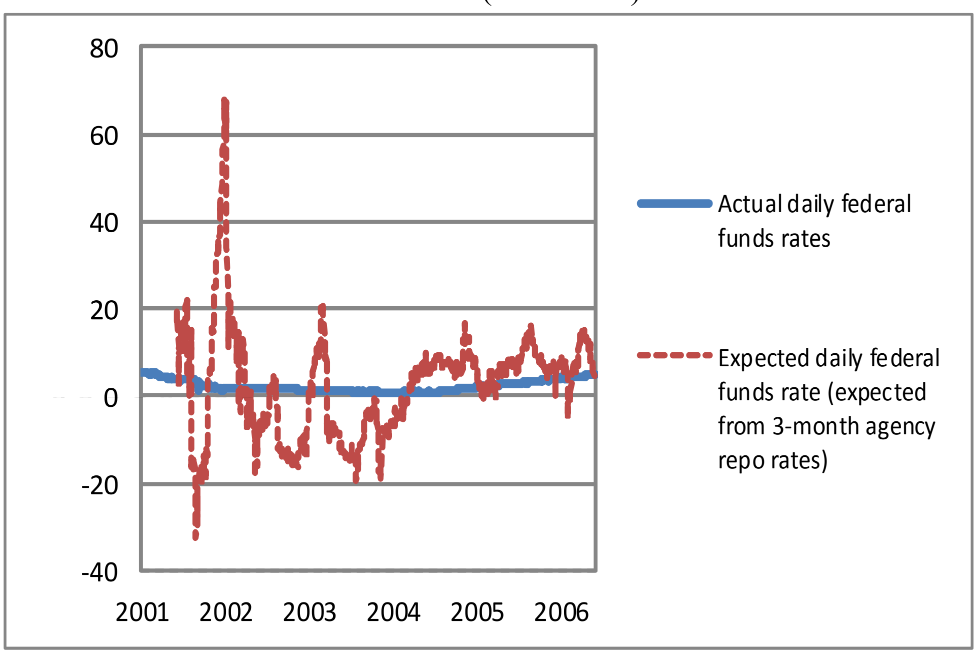
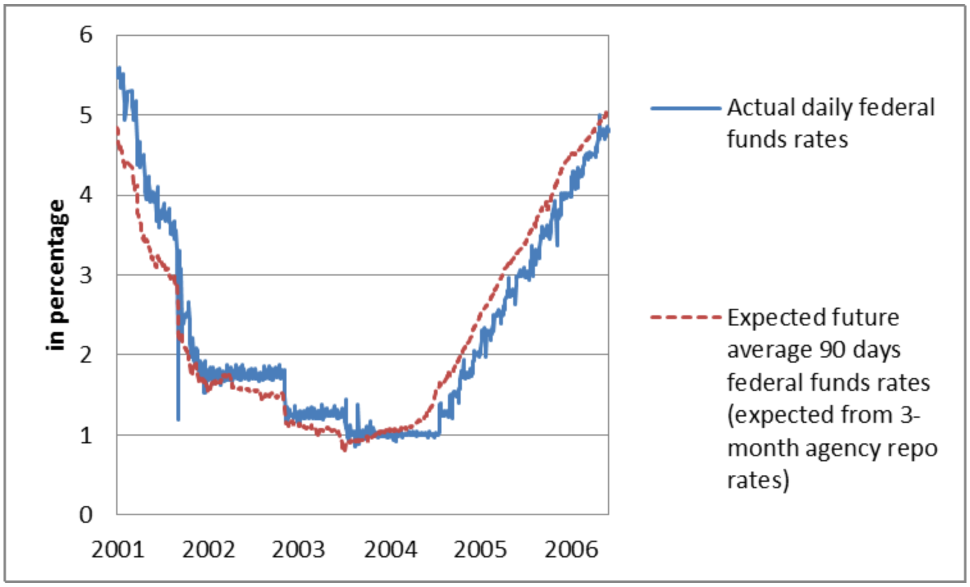


Figure 2. 3 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month agency repo rates (2001-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are very close to actual average 90 day federal funds rates. However, expected daily federal funds rates are far biased from the actual daily federal funds rates.

Furthermore, if the actual daily federal funds rate is above the expected average 90 day federal funds rate, then it will be dragged down. If the actual daily federal funds rate is below the expected average 90 day federal funds rate, then it will be pulled up. This is very meaningful, because expected average 90 day federal funds rates are the estimation on the future 90 day federal funds rates on average. At any point in time, if the actual daily federal funds rate is biased from the expected average 90 day federal funds rates, then it will eventually get back to the expected average level. This works very well because the expected average 90 day federal funds rates are very close to the actual average 90 day federal funds rates.

2.5.2 Expected federal funds rates from government repo rates (2001-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month government repo rates.The estimated coefficients are b_0 = -.1101518, b_1=0.9734084, b_2=.7525485. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the government repo rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). Finaly, after getting both estimated average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.4 through 2.6)

Figure 2. 4 Actual and expected average 90 day federal funds rates from 3-month government repo rates (2001-2006)

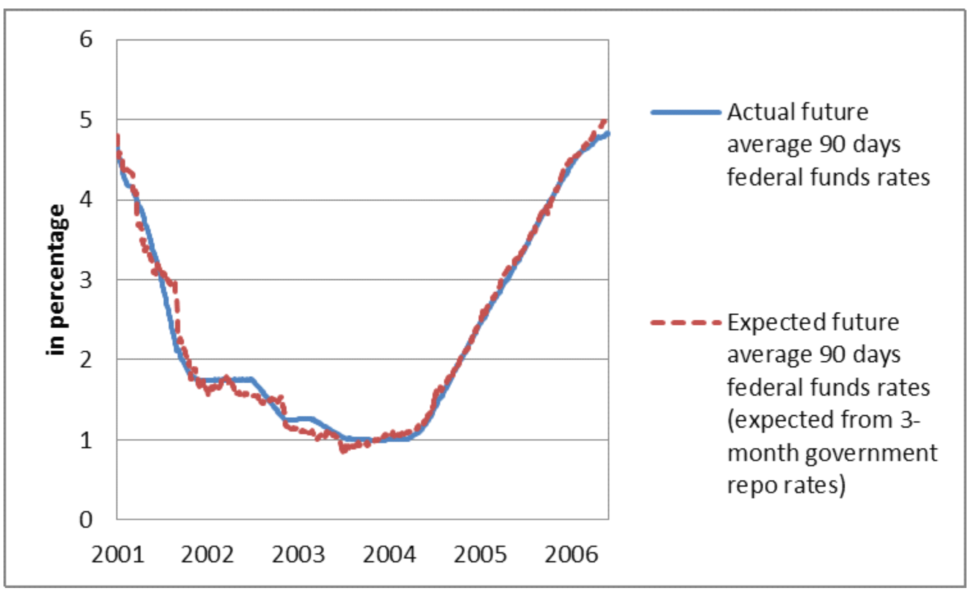


Figure 2. 5 Actual and expected daily federal funds rate from 3-month government repo rates (2001-2006)

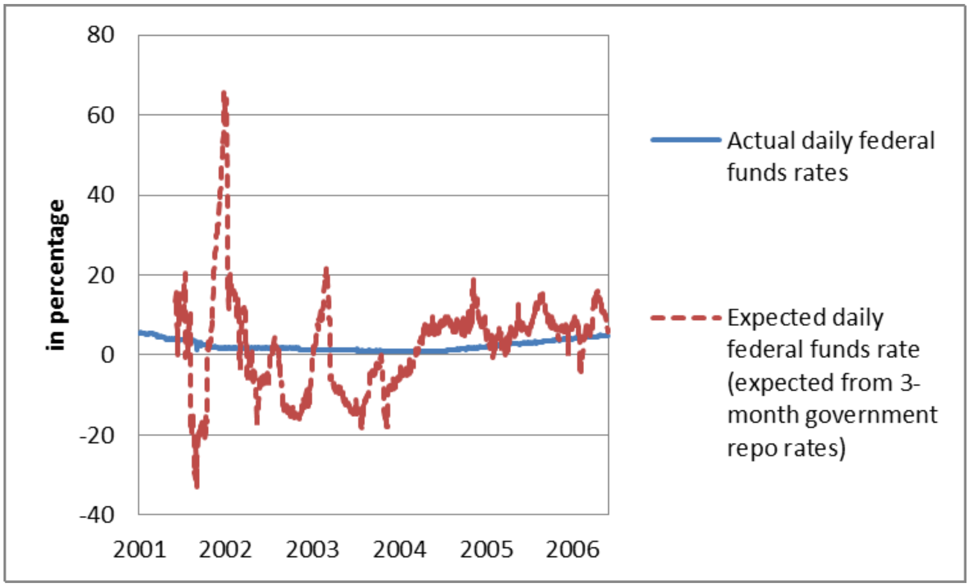
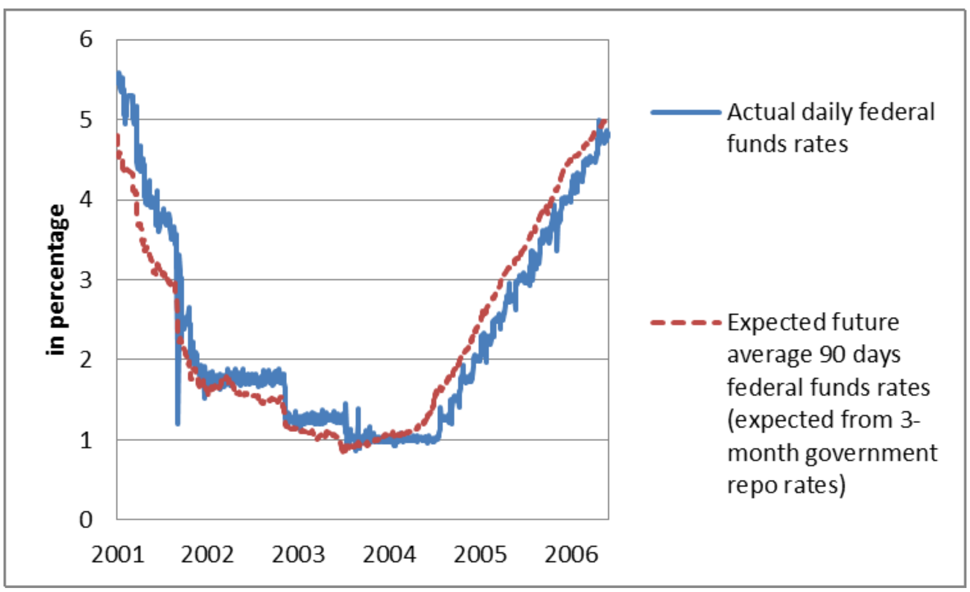


Figure 2. 6 Actual daily federal funds rate and expected average 90 days federal funds rates from 3-month government repo rates (2001-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are very close to actual average 90 day federal funds rates. However, expected daily federal funds rates are far biased from the actual daily federal funds rates.

Furthermore, if the actual daily federal funds rate is above the expected average 90 days federal funds rate, then it will be dragged down. If the actual daily federal funds rate is below the expected average 90 days federal funds rate, then it will be pulled up. This is very meaningful, because expected average 90 day federal funds rates are the estimation on the future 90 days federal funds rates on average. At any point in time, if the actual daily federal funds rate is biased from the expected average 90 day federal funds rates, then it will eventually get back to the expected average level. This works very well because the expected average 90 day federal funds rates are very close to the actual average 90 day federal funds rates.

2.5.3 Expected federal funds rates from mortgage repo rates (2001-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month mortgage repo rates.The estimated coefficients are b_0 = -.1264201, b_1=9785054, b_2=7754894. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the mortgage repo rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). After getting both average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.7 through 2.9)

Figure 2. 7 Actual and expected average 90 day federal funds rates from 3-month mortgage repo rates (2001-2006)

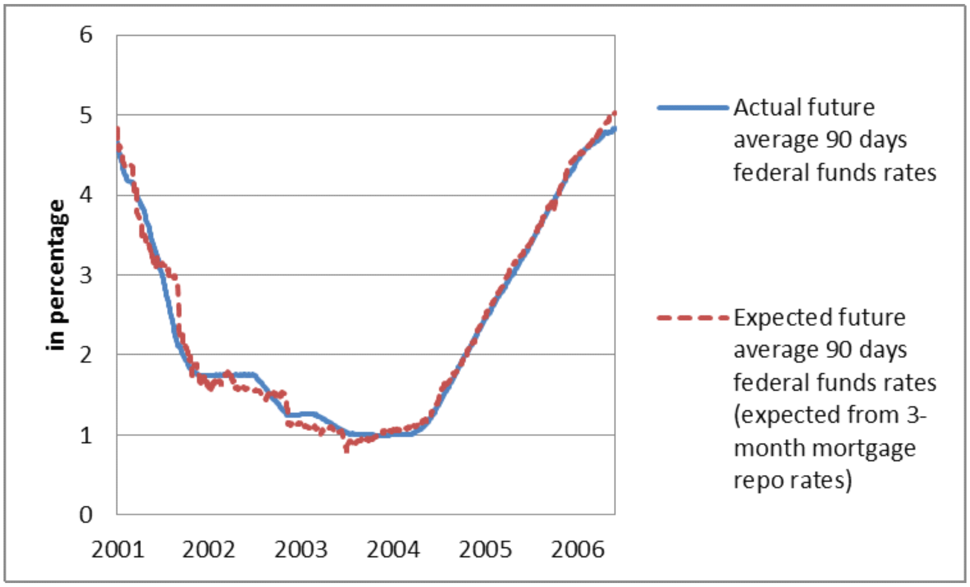


Figure 2. 8 Actual and expected daily federal funds rates from 3-month mortgage repo rates (2001-2006)

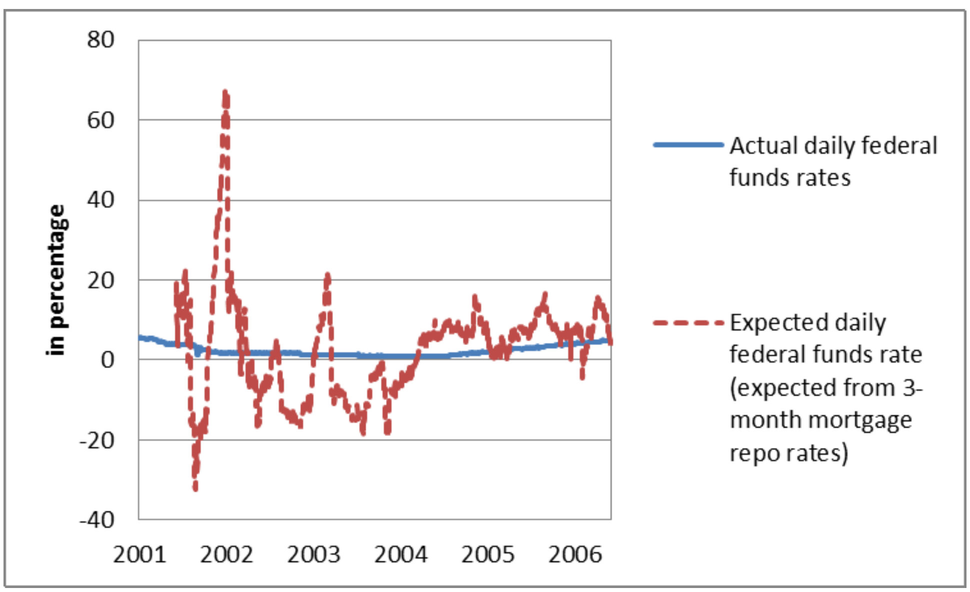
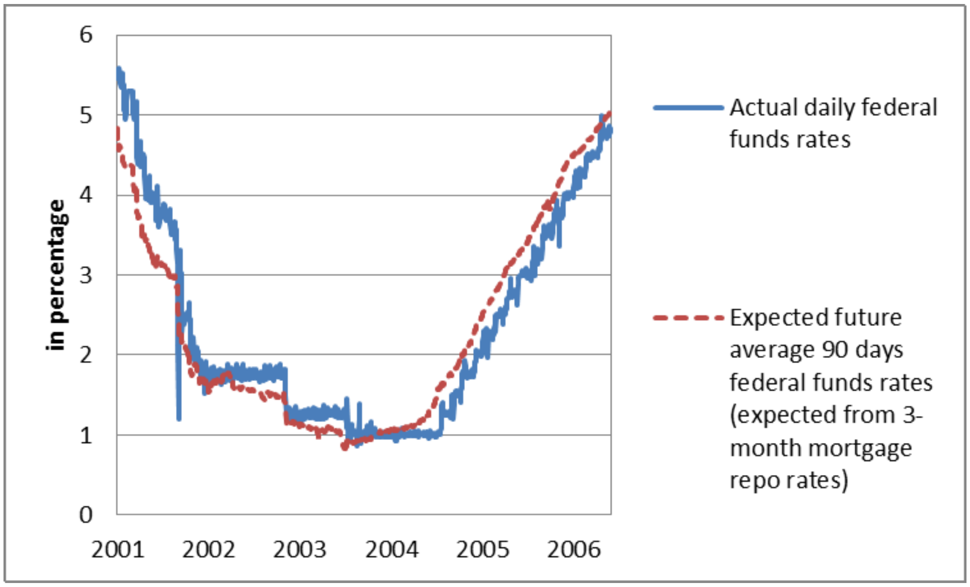


Figure 2. 9 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month mortgage repo rates (2001-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are very close to actual average 90 day federal funds rates. However, expected daily federal funds rates are far biased from the actual daily federal funds rates.

Furthermore, if the actual daily federal funds rate is above the expected average 90 day federal funds rate, then it will be dragged down. If the actual daily federal funds rate is below the expected average 90 day federal funds rate, then it will be pulled up. This is very meaningful, because expected average 90 day federal funds rates are the estimation on the future 90 day federal funds rates on average. At any point in time, if the actual daily federal funds rate is biased from the expected average 90 day federal funds rates, then it will eventually get back to the expected average level. This works very well because the expected average 90 day federal funds rates are very close to the actual average 90 day federal funds rates.

2.5.4 Expected federal funds rates from Treasury bill rates (2001-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month Treasury bill rates.The estimated coefficients are $b_0 =$ -.1096741, b_1=1.505271, b_2=1.365926. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the Treasury bill rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). After getting both average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.10 through 2.12)

Figure 2. 10 Actual and expected average 90 day federal funds rates from 3-month Treasury bill rates (2001-2006)

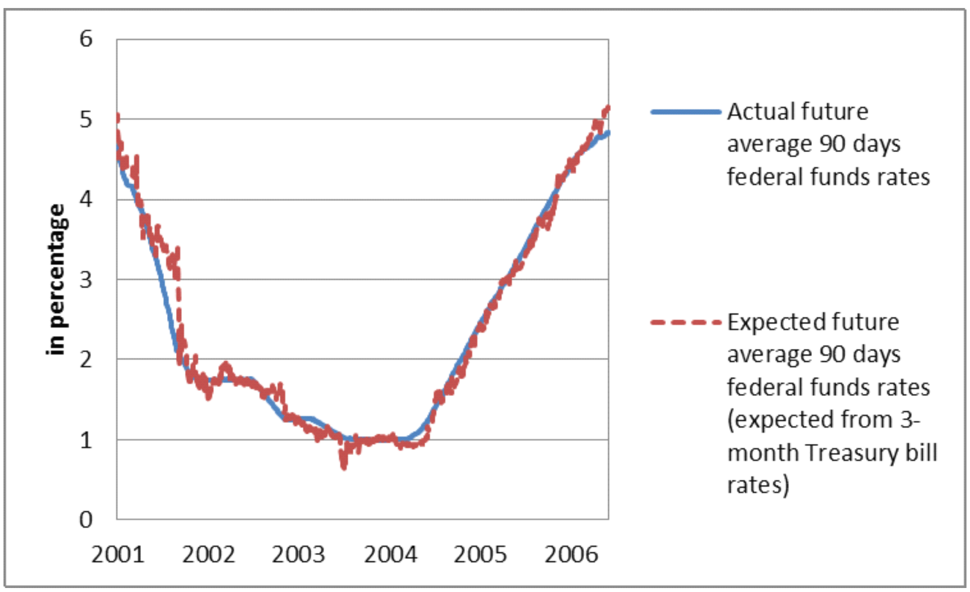


Figure 2. 11 Actual and expected daily federal funds rates from 3-month Treasury bill rates (2001-2006)

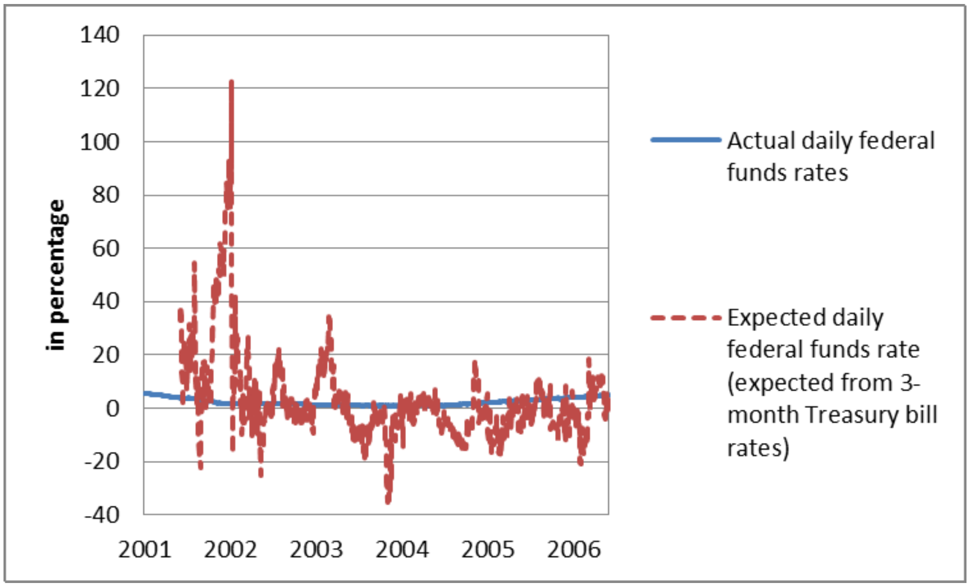
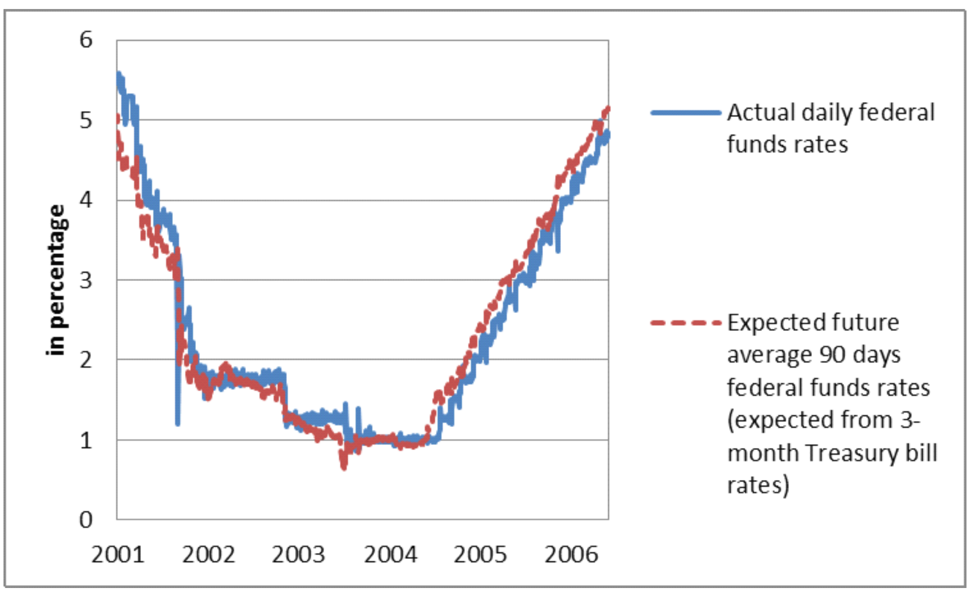


Figure 2. 12 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month Treasury bill rates (2001-2006)



The estimated daily federal funds rates are more biased from the actual rates when using Treasury bill rates instead of repo rates.

From figure 2.10, it seems that the expected average 90 day federal funds rates are also close to the actual rates by using Treasury bill rates. However, the forecasting ability of Treasury bill rates is a little bit weaker than that of repo rates. To show this, we need further exploration.

2.5.5 Comparison of forecasting abilities of three types of repo rates and Treasury bill rates for monetary policy (2001-2006)

Table 2.49 Comparison of forecasting abilities of three types of repo rates and Treasury bill rates for monetary policy (2001-2006)

	Mean square between expected average and actual average 90 day federal funds rates	Mean square between expected and actual daily federal funds rates	Mean square between expected average 90 day federal funds rates and actual daily federal funds rates
Expected from Treasury bill rates	0.037676829468	293.93496007	0.10076312952
Expected from agency repo rates	0.018975715442	154.96575187	0.13999384823
Expected from government repo rates	0.01816308068	148.68226128	0.14448739344
Expected from mortgage repo rates	0.018992110672	155.26653184	0.14046837937

Agency, government and mortgage repo rates have much better ability for forecasting both daily and expected average 90 day federal funds rates than Treasury bill rates.

The forecasting abilities of agency, government and mortgage repo rates are very similar. Government repo rates have slightly better forecasting abilities for both daily and expected average 90 day federal funds rates than do agency and mortgage repo rates during the sample years 2001 through 2006.

2.6 Expected daily and future average 90 day federal funds rates (1991-2006)

From the previous section, this paper found that 3-month agency, government and mortgage repo rates have a much better ability for forecasting both daily and expected average 90 day federal funds rates than Treasury bill rates during the sample period from 2001 through 2006. This paper would like to test a longer sample period from 1991 through 2006 and see whether the same results would be obtained. In this section, both daily federal funds rates and average 90 day federal funds rates will be estimated from 3-month agency repo rates, government repo rates, mortgage repo rates and Treasury bill rates.

2.6.1 Expected from agency repo rates (1991-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month agency repo rates. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the agency repo rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). Finally, after getting both estimated average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.13 through 2.15)

Figure 2.13 Actual and expected average 90 day federal funds rates from 3-month agency repo rates (1991-2006)

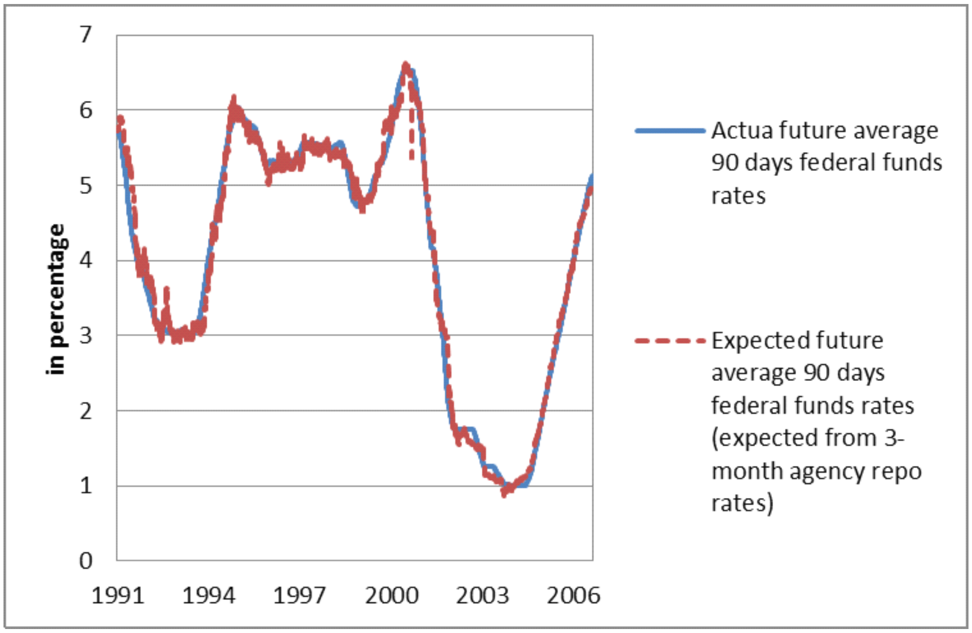


Figure 2.14 Actual and expected daily federal funds rates from 3-month agency repo rates (1991-2006)

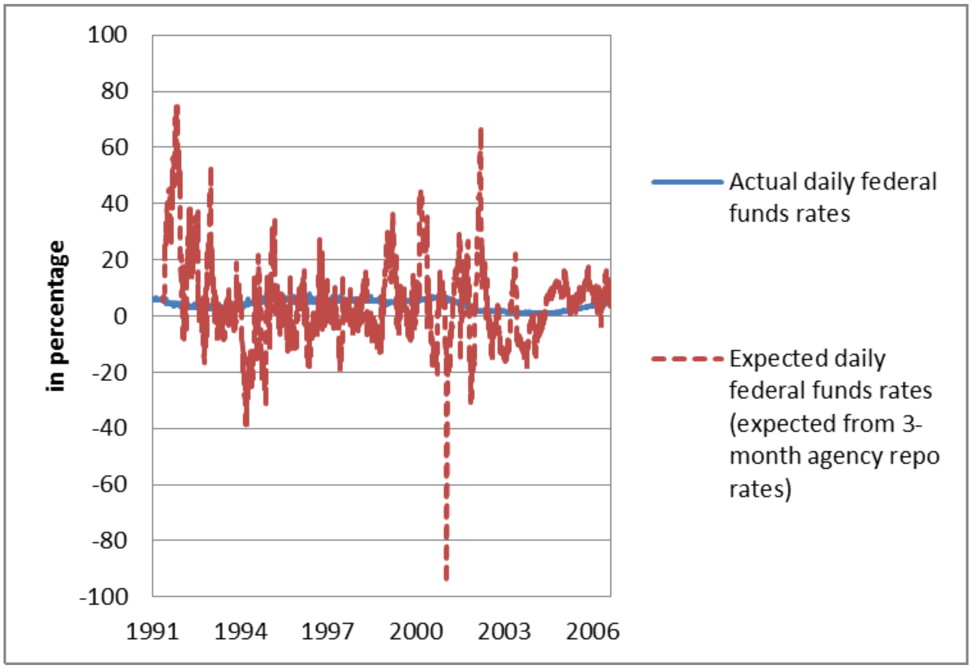
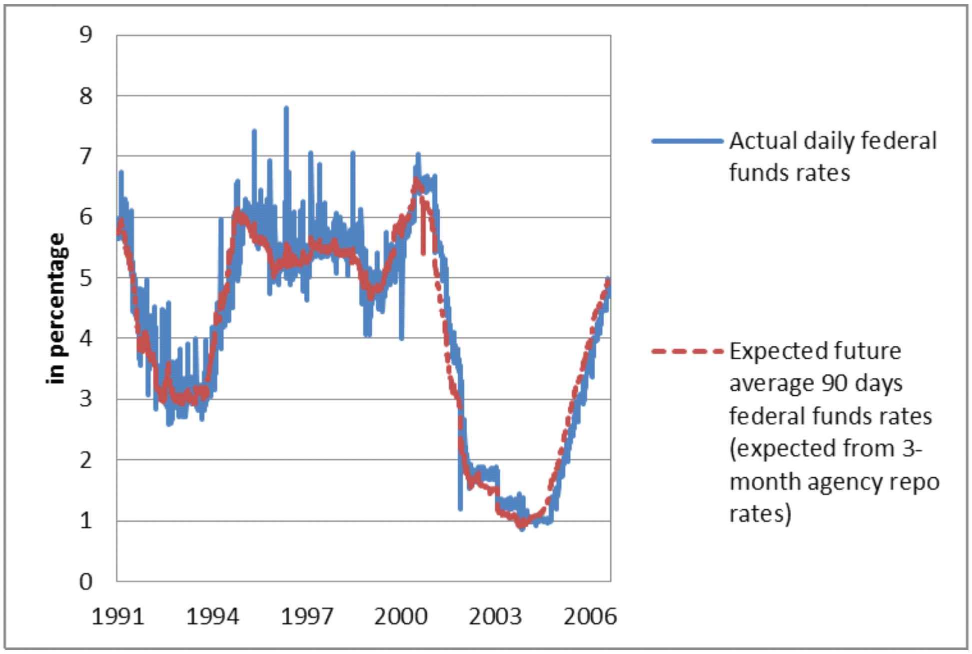


Figure 2.15 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month agency repo rates (1991-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are very close to actual average 90 day federal funds rates. However, expected daily federal funds rates are far biased from the actual daily federal funds rates. Furthermore, actual daily federal funds rates are very close to expected average 90 day federal funds rate during the sample period from 1991 to 2006.

2.6.2 Expected federal funds rates from government repo rates (1991-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month government repo rates. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the government repo rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). Finaly, after getting both estimated average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.16 through 2.18)

Figure 2.16 Actual and expected average 90 day federal funds rates from 3-month government repo rates (1991-2006)

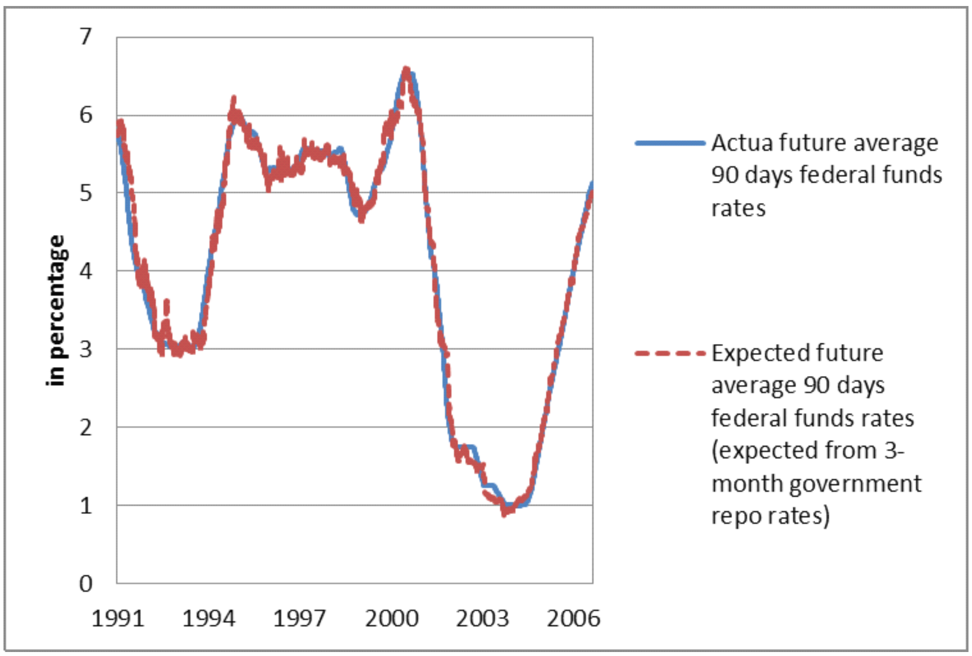


Figure 2.17 Actual and expected daily federal funds rates from 3-month government repo rates (1991-2006)

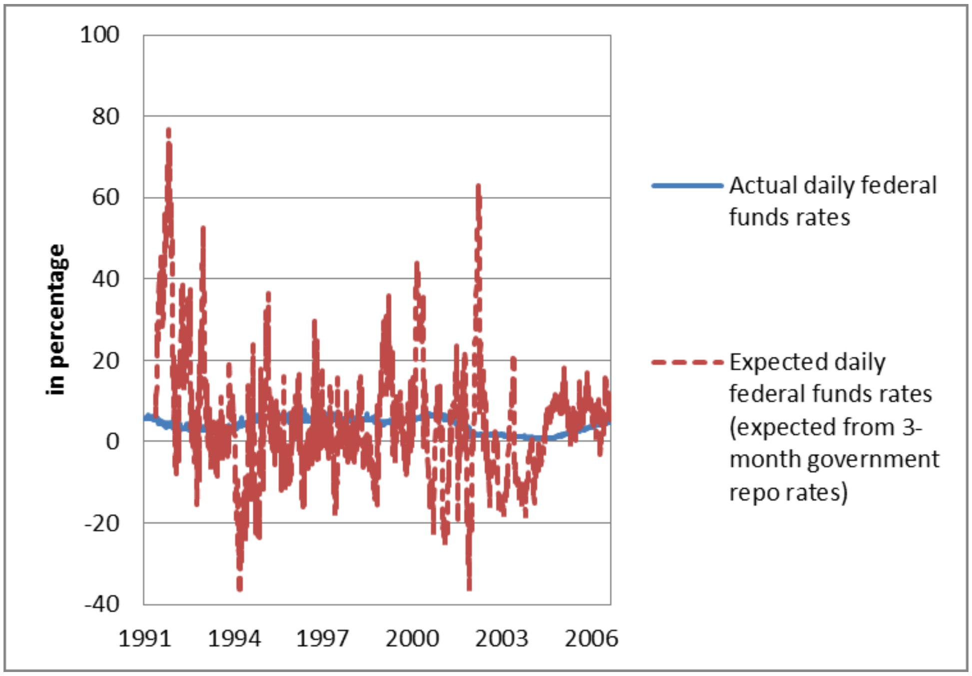
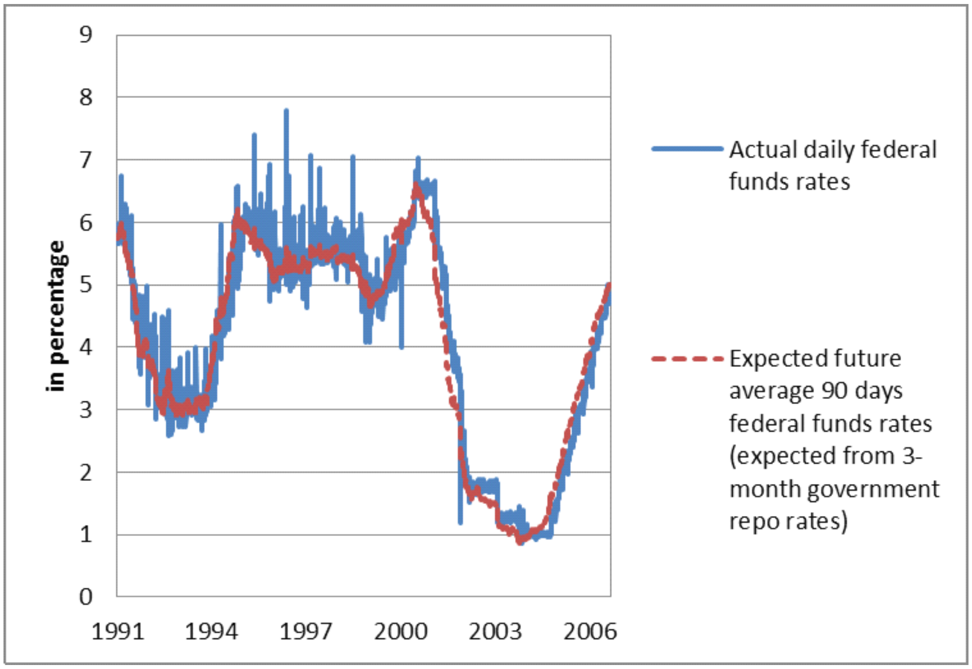


Figure 2.18 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month government repo rates (1991-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are very close to actual average 90 day federal funds rates. However, expected daily federal funds rates are far biased from the actual daily federal funds rates. Furthermore, actual daily federal funds rates are very close to expected average 90 day federal funds rate during the sample period from 1991 to 2006.

2.6.3 Expected federal funds rates from mortgage repo rates (1991-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month mortgage repo rates. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the mortgage repo rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). After getting both average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.19 through 2.21)

Figure 2.19 Actual and expected average 90 day federal funds rates from 3-month mortgage repo rates (1991-2006)

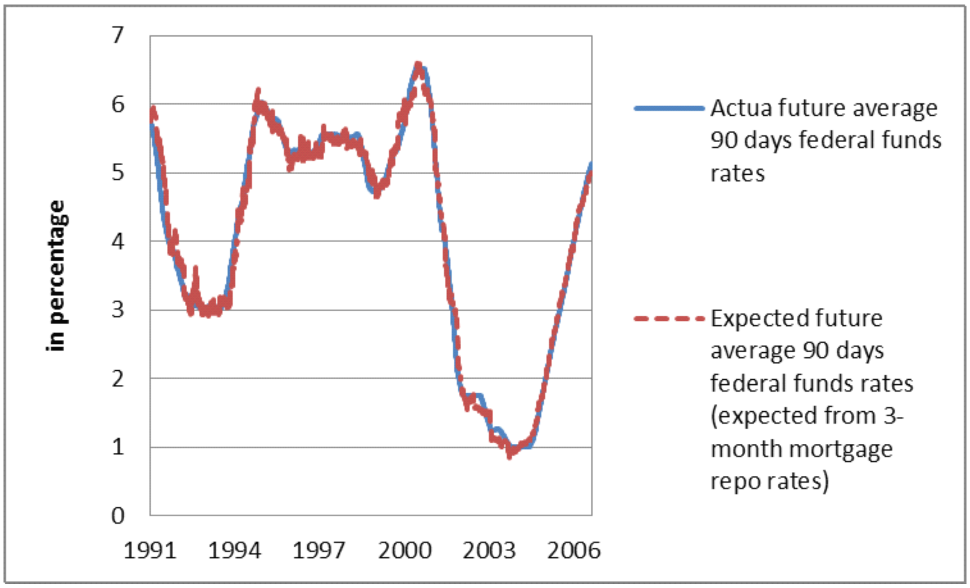


Figure 2.20 Actual and expected daily federal funds rates from 3-month mortgage repo rates (1991-2006)

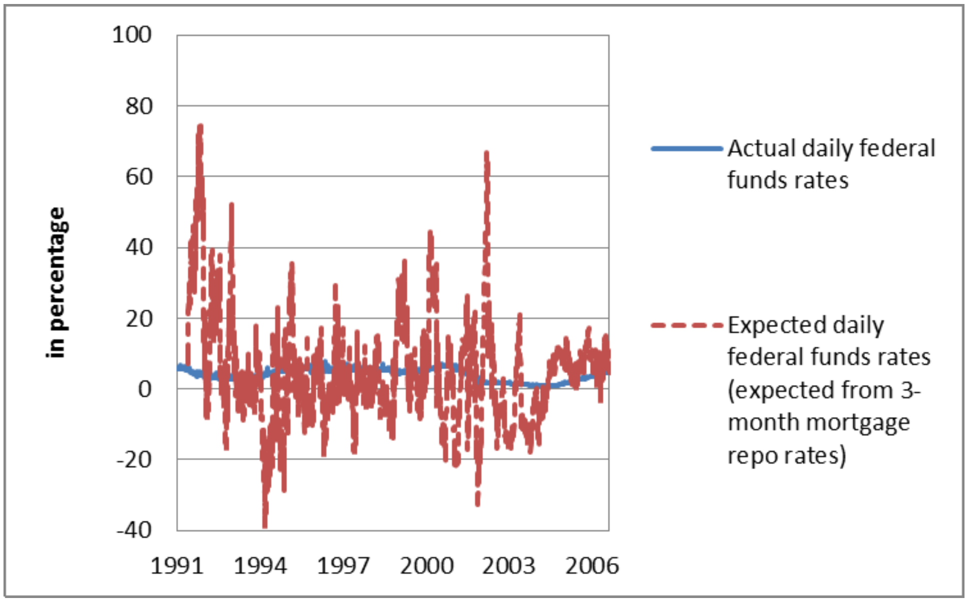
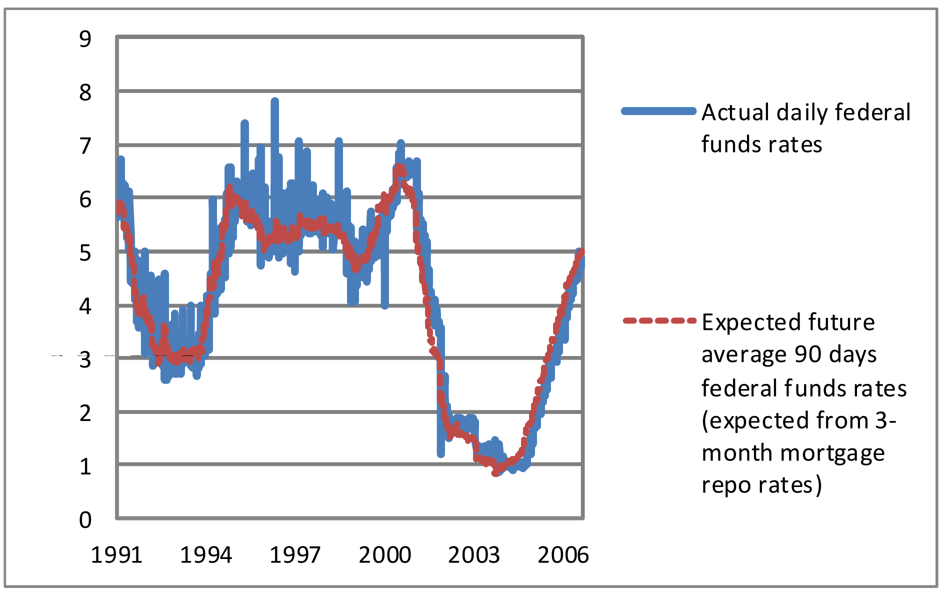


Figure 2.21 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month mortgage repo rates (1991-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are very close to actual average 90 day federal funds rates. However, expected daily federal funds rates are far biased from the actual daily federal funds rates. Furthermore, actual daily federal funds rates are very close to expected average 90 day federal funds rate during the sample period from 1991 to 2006.

2.6.4 Expected from Treasury bill rates (1991-2006)

In this section, both average 90 day federal funds rates and daily federal funds rates will be forecasted by using 3-month Treasury bill rates. All of the estimated coefficients are significantly different from zero at a 5% significance level. RRA in this section represents the Treasury bill rate. REURO is the 3-month Euro dollar rate.

Firstly, this section will use equation (22) to get the expected average 90 day federal funds rates. Secondly, we will forecast daily federal funds rates by applying equation (23). After getting both average 90 day federal funds rates and daily federal funds rates, this section will present three graphs to show the estimation results. (See figures 2.22 through 2.24)

Figure 2.22 Actual and expected average 90 day federal funds rates from 3-month Treasury bill rates (1991-2006)

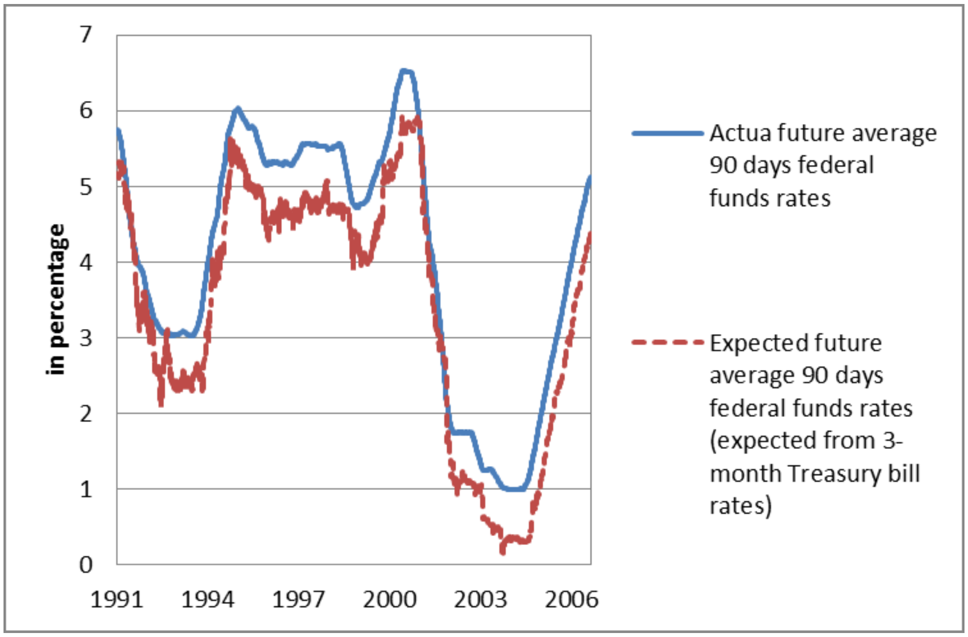


Figure 2.23 Actual and expected daily federal funds rates from 3-month Treasury bill rates (1991-2006)

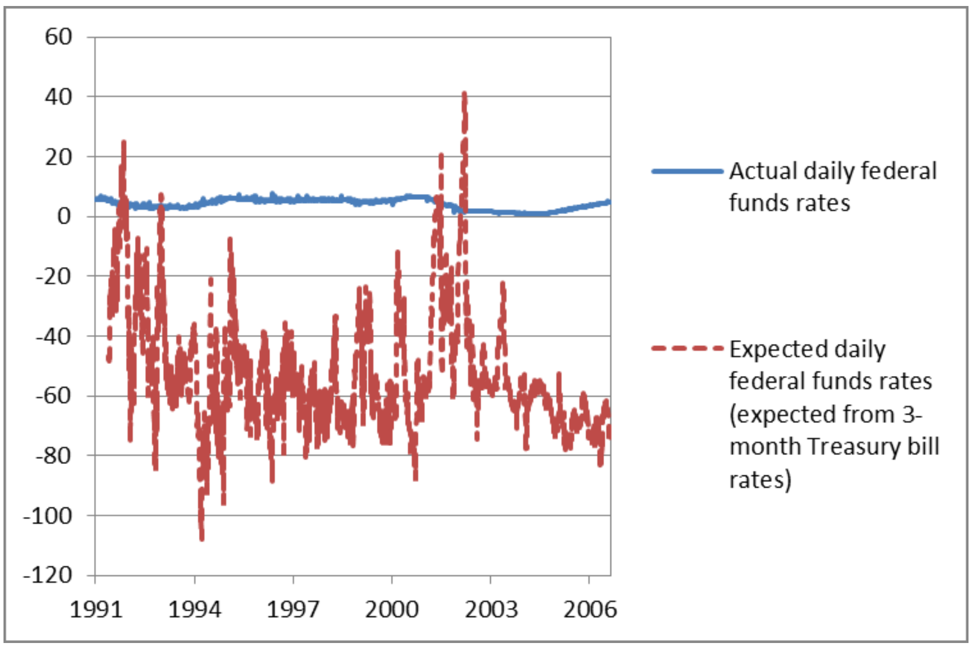
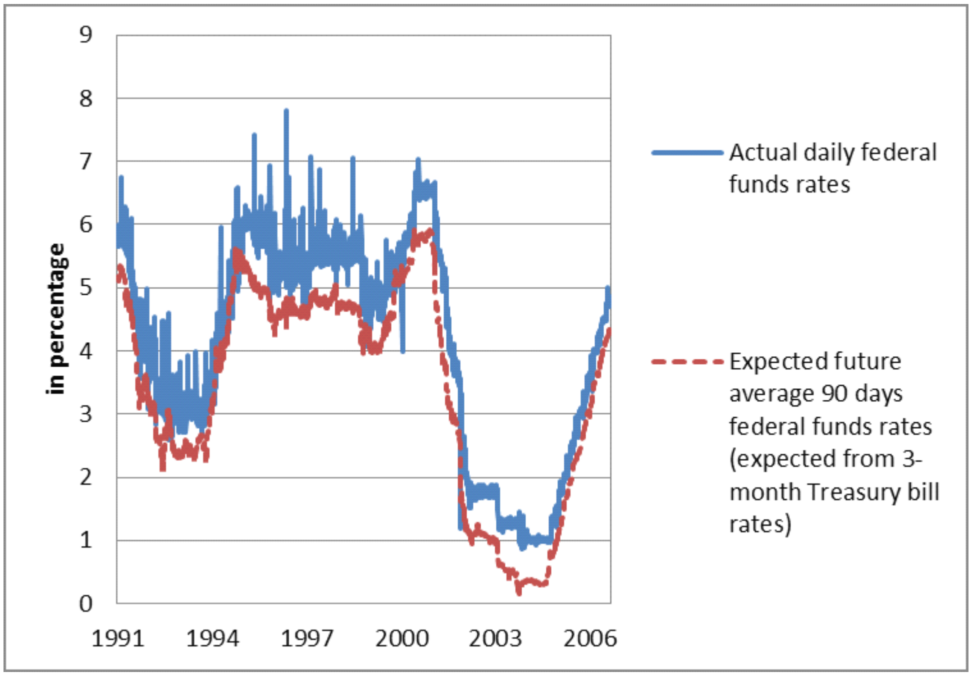


Figure 2.24 Actual daily federal funds rates and expected average 90 day federal funds rates from 3-month Treasury bill rates (1991-2006)



These graphs demonstrate that expected future average 90 day federal funds rates are below the actual average 90 day federal funds rates. The expected daily federal funds rates are far biased from the actual daily federal funds rates. Furthermore, actual daily federal funds rates are above the expected average 90 day federal funds rate during the sample period from 1991 to 2006.

2.6.5 Comparison of forecasting abilities of three types of repo rates and Treasury bill rates for monetary policy (1991-2006)

Table 2.50 Comparison of forecasting abilities of three types of repo rates and Treasury bill rates for monetary policy (1991-2006)

	Mean square between expected and actual average 90 day federal funds rates	Mean square between expected and actual daily federal funds rates	Mean square between expected average 90 day federal funds rates and actual daily federal funds rates
Expected from Treasury bill rates	0.45094584969	3608.5945711	0.49965135068
Expected from agency repo rates	0.029662844679	236.73407341	0.11051199552
Expected from government repo rates	0.028686136325	229.4899296	0.11456172924
Expected from mortgage repo rates	0.029556223786	236.01704806	0.11198864207

Agency, government and mortgage repo rates have much better ability for forecasting both daily and expected average 90 day federal funds rates than Treasury bill rates.

The forecasting abilities of agency, government and mortgage repo rates are very similar. Government repo rates have slightly better forecasting abilities for both daily and expected average 90 day federal funds rates than do agency and mortgage repo rates during the sample years 1991 through 2006.

2.7 Conclusions

Firstly, expectation theory is found to work extremely well by using 3-month repo rates instead of Treasury bill rates, since the repurchase agreements are very efficient money market instruments. The repurchase agreements are the first widely used money market instruments, while the Treasury bill rates ranked the fifth. This result is consistent with Longstaff's (2000) finding. Longstaff (2000) found evidence to support pure expectation hypothesis by using shorter term repo rate. In other words, long term repo rates can forecast the average future overnight repo rates very well. By ignoring the recent abnormal data resulting from the financial crisis, the expectation theory works better by applying 1-month or 3-month repo rates. Furthermore, the expectation theory works extremely well by using 3-month repo rates, which again tells us the importance of good quality data. However, not all the data is within control, for example: federal funds rates came very close to 0. The abnormal federal funds rate data confuses the market expectations for the economy, and it is out of control. Under that specific circumstance, the Federal Reserve had to lower the federal funds rate as much as it can.

Secondly, this paper tried to explore why the expectation theory works not as well when using 1-month repo rates instead of 3-month repo rates. One may think that it is because the average 90 day federal funds rates are easier to be captured by the market, because it is less volatile than the average 30 day federal funds rates. However, the statistics show that the average 90 day federal funds rates are more volatile than the average 30 day federal funds rates. Please see table 2.41 and 2.42. Further research may be needed to pin point the underlying resons for the different results.

Thirdly, the expectation theory performs a lot better by applying repo rates instead of Treasury bill rates as risk free rates. This may suggest that repo rates might be better risk free rates than Treasury bill rates. However, this paper did not find evidence to support the pure form of expectation theory, because the coefficient on term premium is significantly different from zero.

Last but not least, 3-month repo rates could forecast the average 90 day federal funds rates very well. To to be more specific, agency, government and mortgage repo rates have a much better ability for forecasting both daily and expected average 90 day federal funds rates than Treasury bill rates. The forecasting abilities of agency, government and mortgage repo rates are very similar. Government repo rates have slightly better forecasting abilities for both daily and expected average 90 day federal funds rates than do agency and mortgage repo rates during both the sample periods from 2001 to 2006 and from 1991 to 2006.

Table 2.5 The expectation performance of 3-month Treasury bill rates (Equation 12)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.855132**	.0161927	52.81	0.000	.8233872	.8868769
b_2	-.0000239	.0116297	-0.00	0.998	-.0228233	.0227755
Constant (b_0)	.0963647**	.0053433	18.03	0.000	.0858896	.1068399

Table 2.6 The expectation performance of 3-month mortgage repo rates (Equation 13)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3878825**	.0151705	25.57	0.000	.3581416	.4176235
b_2	.0797492**	.0158428	5.03	0.000	.0486904	.1108081
Constant (b_0)	-.0399339**	.0046549	-8.58	0.000	-.0490597	-.0308082

Table 2.7 The expectation performance of 3-month agency repo rates (Equation 14)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.4872037**	.0081857	59.52	0.000	.4711561	.5032512
b_2	.1993339**	.0081372	24.50	0.000	.1833813	.2152865
Constant (b_0)	-.0420987**	.0035916	-11.72	0.000	-.0491397	-.0350577

Table 2.8 The expectation performance of 3-month government repo rates (Equation 15)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3844628**	.0154654	24.86	0.000	.3541437	.4147819
b_2	.0795327**	.0160495	4.96	0.000	.0480687	.1109968
Constant (b_0)	-.0302655**	.0046643	-6.49	0.000	-.0394097	-.0211213

Table 2.9 The expectation performance of 3-month mortgage repo rates (Equation 16)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3735851**	.0158267	23.60	0.000	.3425578	.4046124
b_2	.0775843**	.0163398	4.75	0.000	.0455512	.1096175
Constant (b_0)	-.0157315 **	.0047496	-3.31	0.001	-.0250428	-.0064201

Table 2.10 The expectation performance of 3-month agency repo rates (Equation 17)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3841263**	.0160283	23.97	0.000	.3527037	.4155488
b_2	.0784544**	.0161034	4.87	0.000	.0468845	.1100242
Constant (b_0)	-.0339335**	.0053848	-6.30	0.000	-.0444901	-.023377

Table 2.11 The expectation performance of 3-month government repo rates (Equation 18)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.2939622**	.0059066	49.77	0.000	.2823825	.3055418
b_2	-.033072**	.0117251	-2.82	0.005	-.0560583	-.0100857
Constant (b_0)	.0176868**	.0054562	3.24	0.001	.0069902	.0283834

Table 2.12 The expectation performance of 3-month mortgage repo rates (Equation 19)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3065694**	.005354	57.26	0.000	.2960731	.3170656
b_2	-.0291434**	.0113536	-2.57	0.010	-.0514014	-.0068854
Constant (b_0)	-.0074219	.0054261	-1.37	0.171	-.0180595	.0032157

Table 2.13 The expectation performance of 3-month agency repo rates (Equation 20)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3033689 **	.00569	53.32	0.000	.292214	.3145238
b_2	-.0291796	.0116202	-2.51	0.012	-.0519604	-.0063988
Constant (b_0)	.0021564**	.0054762	0.39	0.694	-.0085794	.0128921

Table 2.14 The expectation performance of 1-month Treasury bill rates [Equation (12)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.2257429**	.0138744	16.27	0.000	.198535	.2529508
b_2	.121209**	.0117501	10.32	0.000	.098167	.144251
Constant (b_0)	-.0037245	.0037978	-0.98	0.327	-.0111721	.003723

Table 2.15 The expectation performance of 1-month mortgage repo rates [Equation (13)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1953029**	.0126252	15.47	0.000	.1705447	.220061
b_2	.1217386**	.0127657	9.54	0.000	.096705	.1467721
Constant (b_0)	-.0288104**	.0036811	-7.83	0.000	-.0360292	-.0215917

Table 2.16 The expectation performance of 1-month agency repo rates [Equation (14)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1906754**	.0126955	15.02	0.000	.1657793	.2155715
b_2	.1220119**	.0130206	9.37	0.000	.0964783	.1475455
Constant (b_0)	-.0278997**	.0037066	-7.53	0.000	-.0351684	-.0206311

Table 2.17 The expectation performance of 1-month government repo rates [Equation (15)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1953356**	.0128761	15.17	0.000	.1700855	.2205858
b_2	.121782**	.013151	9.26	0.000	.0959927	.1475713
Constant (b_0)	-.0218126**	.0036892	-5.91	0.000	-.0290471	-.0145781

Table 2.18 The expectation performance of 1-month mortgage repo rates [Equation (16)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1873153**	.011473	16.33	0.000	.1648166	.209814
b_2	.1191608**	.0120271	9.91	0.000	.0955755	.142746
Constant (b_0)	-.0406685**	.004591	-8.86	0.000	-.0496715	-.0316656

Table 2.19 The expectation performance of 1-month agency repo rates [Equation (17)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.171021**	.0105356	16.23	0.000	.1503605	.1916814
b_2	.1113974**	.0114487	9.73	0.000	.0889465	.1338483
Constant (b_0)	-.035732**	.0043784	-8.16	0.000	-.0443181	-.0271458

Table 2.20 The expectation performance of 1-month government repo rates [Equation (18)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1163421**	.0054024	21.54	0.000	.105748	.1269362
b_2	.0590414**	.0056858	10.38	0.000	.0478914	.0701914
Constant (b_0)	-.0219031**	.0036865	-5.94	0.000	-.0291324	-.0146738

Table 2.21 The expectation performance of 1-month mortgage repo rates [Equation (19)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1148022**	.0051406	22.33	0.000	.1047215	.1248829
b_2	.0612715**	.0055851	10.97	0.000	.050319	.072224
Constant (b_0)	-.034387**	.0040555	-8.48	0.000	-.04234	-.0264341

Table 2.22 The expectation performanc of 1-month agency repo rates [Equation (20)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1077169**	.0048148	22.37	0.000	.0982749	.1171588
b_2	.0598584**	.0054223	11.04	0.000	.0492253	.0704915
Constant (b_0)	-.0320661**	.0040081	-8.00	0.000	-.0399261	-.0242062

Table 2.23 The expectation performance of 1-month Treasury bill rates [Equation (12)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.5078731**	.0239359	21.22	0.000	.4609183	.5548278
b_2	.3662564**	.0161158	22.73	0.000	.3346424	.3978704
Constant (b_0)	-.0435749**	.0047618	-9.15	0.000	-.0529161	-.0342337

Table 2.24 The expectation performance of 1-month mortgage repo rates [Equation (13)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.4148832**	.0315661	13.14	0.000	.3529605	.4768059
b_2	.3860716**	.0437623	8.82	0.000	.3002239	.4719193
Constant (b_0)	-.0663248**	.0048679	-13.62	0.000	-.075874	-.0567755

Table 2.25 The expectation performance of 1-month agency repo rates [Equation (14)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.4171425**	.0309221	13.49	0.000	.3564831	.4778019
b_2	.3907178**	.0421999	9.26	0.000	.3079348	.4735007
Constant (b_0)	-.0666181**	.0048661	-13.69	0.000	-.0761638	-.0570723

Table 2.26 The expectation performance of 1-month government repo rates [Equation (15)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.4047939**	.0317687	12.74	0.000	.3424738	.4671139
b_2	.3616862**	.0465842	7.76	0.000	.2703027	.4530697
Constant (b_0)	-.0619716**	.0051314	-12.08	0.000	-.0720377	-.0519054

Table 2.27 The expectation performance of 1-month mortgage repo rates [Equation (16)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.2948247**	.0303059	9.73	0.000	.2353742	.3542752
b_2	.2614054**	.0505192	5.17	0.000	.1623028	.360508
Constant (b_0)	-.0768651**	.007789	-9.87	0.000	-.0921446	-.0615856

Table 2.28 The expectation performance of 1-month agency repo rates [Equation (17)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.2735823**	.0305355	8.96	0.000	.2136814	.3334833
b_2	.2403429**	.0524035	4.59	0.000	.1375438	.343142
Constant (b_0)	-.073822**	.0080607	-9.16	0.000	-.0896346	-.0580095

Table 2.29 The expectation performance of 1-month government repo rates [Equation (18)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	1478132**	.0081505	18.14	0.000	.1318244	.1638019
b_2	.0448425**	.0201798	2.22	0.026	.0052562	.0844288
Constant (b_0)	-.0327561**	.0047726	-6.86	0.000	-.0421184	-.0233938

Table 2.30 The expectation performance of 1-month mortgage repo rates [Equation (19)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1266883**	.0072008	17.59	0.000	.1125625	.1408141
b_2	.0563003**	.0205597	2.74	0.006	.0159686	.096632
Constant (b_0)	-.0455574**	.0051205	-8.90	0.000	-.0556021	-.0355126

Table 2.31 The expectation performance of 1-month agency repo rates [Equation (20)']

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.1215584**	.006958	17.47	0.000	.107909	.1352078
b_2	.0656178**	.0203237	3.23	0.001	.0257491	.1054864
Constant (b_0)	-.0474277**	.0051912	-9.14	0.000	-.0576111	-.0372442

Table 2.32 The expectation performance of 3-month Treasury bill rates (Equation 12)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	1.505271**	.0806001	18.68	0.000	1.347159	1.663383
b_2	1.365926**	.0630549	21.66	0.000	1.242233	1.48962
Constant (b_0)	-.1096741**	.0118327	-9.27	0.000	-.1328861	-.0864622

Table 2.33 The expectation performance of 3-month mortgage repo rates (Equation 13)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.9785054**	.0320247	30.55	0.000	.915683	1.041328
b_2	.7754894**	.0371179	20.89	0.000	.7026759	.848303
Constant (b_0)	-.1264201**	.0065446	-19.32	0.000	-.1392585	-.1135817

Table 2.34 The expectation performance of 3-month agency repo rates (Equation 14)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.9844044**	.0325848	30.21	0.000	.9204834	1.048325
b_2	.7834065**	.0376714	20.80	0.000	.7095072	.8573057
Constant (b_0)	-.1271211**	.0065964	-19.27	0.000	-.1400612	-.114181

Table 2.35 The expectation performance of 3-month government repo rates (Equation 15)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.9734084**	.030659	31.75	0.000	.9132651	1.033552
b_2	.7525485**	.0362521	20.76	0.000	.6814333	.8236636
Constant (b_0)	-.1101518**	.0059585	-18.49	0.000	-.1218404	-.0984631

Table 2.36 The expectation performance of 3-month mortgage repo rates (Equation 16)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.7625493**	.0246468	30.94	0.000	.7142	.8108987
b_2	.559231**	.0332487	16.82	0.000	.4940075	.6244544
Constant (b_0)	-.1505104**	.0070069	-21.48	0.000	-.1642557	-.1367651

Table 2.37 The expectation performance of 3-month government repo rates (Equation 17)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.7713213**	.0258084	29.89	0.000	.7206935	.8219491
b_2	.5726701**	.0353386	16.21	0.000	.5033469	.6419933
Constant (b_0)	-.1535444**	.0069762	-22.01	0.000	-.1672296	-.1398592

Table 2.38 The expectation performance of 3-month government repo rates (Equation 18)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3241937**	.0086042	37.68	0.000	.307315	.3410724
b_2	.2746431**	.0419441	6.55	0.000	.192362	.3569242
Constant (b_0)	-.094966	.009365	-10.14	0.000	-.1133371	-.0765948

Table 2.39 The expectation performance of 3-month mortgage repo rates (Equation 19)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3032037**	.0082676	36.67	0.000	.2869853	.3194222
b_2	.2799851**	.0431056	6.50	0.000	.1954256	.3645446
Constant (b_0)	-.1175716**	.0099501	-11.82	0.000	-.1370905	-.0980526

Table 2.40 The expectation performance of 3-month agency repo rates (Equation 20)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.3009399**	.0082479	36.49	0.000	.2847602	.3171197
b_2	.3008489**	.0433827	6.93	0.000	.2157458	.385952
Constant (b_0)	-.1212271**	.0100655	-12.04	0.000	-.1409725	-.1014817

Table 2.41 Summary statistics on the average 90-days federal funds rate

Variable	Obs	Mean	Std. Dev.	Min	Max
sumrff90	1384	4.805195	1.513999	1.557444	7.594444

Table 2.42 Summary statistics on the average 30-days federal funds rate

Variable	Obs	Mean	Std. Dev.	Min	Max
sumrff30	1384	4.752793	1.506104	1.332333	7.356667

Table 2.43 Summary statistics on the 1-month agency repo rate

Variable	Obs	Mean	Std. Dev.	Min	Max
rra1m	1384	2.576582	1.509047	.9	5.33

Table 2.44 Summary statistics on the 3-month agency repo rate

Variable	Obs	Mean	Std. Dev.	Min	Max
rra3m	1384	2.623743	1.530158	.87	5.41

Table 2.45 Test for heteroskedasticity (Equation 12)

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
Variables: fitted values of $\sum_{i=1}^{90} (RFF_{t+i})/90 - RFF_t$
chi2(1) = 315.07
Prob > chi2 = 0.0000

Table 2.46 Test for heteroskedasticity (Equation 13)

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
Variables: fitted values of $\sum_{i=1}^{90} (RFF_{t+i})/90 - RFF_t$
chi2(1) = 1616.63
Prob > chi2 = 0.0000

Table 2.47 Test for heteroskedasticity (Equation 14)

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
Variables: fitted values of $\sum_{i=1}^{90} (RFF_{t+i})/90 - RFF_t$
chi2(1) = 1727.24
Prob > chi2 = 0.0000

Table 2.48 Test for heteroskedasticity (Equation 15)

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
Variables: fitted values of $\sum_{i=1}^{90} (RFF_{t+i})/90 - RFF_t$
chi2(1) = 2071.14
Prob > chi2 = 0.0000

Table 2.51 The expectation performance of 3-month agency repo rates (Equation 14) (1991-2006)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	0.8868378	0.0100245	88.47	0.000	.8671841	.9064916
b_2	0.6669706	0.0118424	56.32	0.000	.6437527	.6901884
Constant (b_0)	-0.01117347	0.002923	-38.23	0.000	-.1174655	-.1060039

Table 2.52 The expectation performance of 3-month government repo rates (Equation 15) (1991-2006)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.8780698	.0098856	88.82	0.000	.8586883	.8974513
b_2	.6361386	.0118835	53.53	0.000	.6128401	.659437
Constant (b_0)	-.1022902	.0028706	-35.63	0.000	-.1079182	-.0966623

Table 2.53 The expectation performance of 3-month mortgage repo rates (Equation 13) (1991-2006)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	.8801673	.0100423	87.65	0.000	.9804785	.899856
b_2	.6556642	.0119347	54.94	0.000	.6322654	.6790631
Constant (b_0)	-.1182219	.0029264	-40.40	0.000	-.1239594	-.1124844

Table 2.54 The expectation performance of 3-month Treasury bill rates (Equation 12) (1991-2006)

	Coef.	Std. Err.	t	P>|t|	[95% Conf. Interval]	
b_1	1.12451	.016392	68.60	0.000	1.092372	1.156647
b_2	.7861445	.0232319	33.84	0.000	.7405967	.8316923
Constant (b_0)	-.0701322	.0067715	-10.36	0.000	-.0834083	-.0568561

3 Chapter 3: Discount rate changes and their effects on market returns during recent U.S. recessions

ABSTRACT

This paper explores the market response to the discount rate changes during the recent U.S. recessions and finds that the response of market rates to discount rate changes varied during the recent two recessions. The different responses of market rates to discount rate changes are due to the various economic and policy circumstances that the market was facing. This conclusion is consistent with Thornton's finding (1998). Thornton (1998) found that the different market responses to the discount rate changes mainly depend on the information content that people believed contained in the announcements of the discount rate changes. It's interesting to point out that during the "Great Recession", market rates were not sensitive to discount rate changes. The underlying reason was the discount rates were above the federal funds rates during the "Great Recession". In other words, the discount window borrowing has lost its function to provide adequate funds to the economy during the recession.

3.1 Background

3.1.1 Discount rate as an important monetary policy instrument

The public is already getting used to consider the federal funds rate as a major monetary policy instrument. Many people were shocked when the Federal Reserve announced to raise the discount rate by 0.25 percent on February, 19, 2010, What is the implication of the Federal Reserve's action? Is it simply a technical change to keep discount rate certain level with the federal funds rate or is it a tightening monetary policy? This study was motivated by these questions and tried to further explore the related area of the discount rate.

The discount rate became monetary instrument in the United States as early as 1907. When the Federal Reserve was first established to fight the Panic of 1907, discount window and discount rate were the only monetary policy instruments.

3.1.2 A new method of establishing the discount rate from 2003

Before 2003, the discount rate was set below the target federal funds rate. From January 2003 up to the crisis in 2007, the discount rate was one percentage point above the target federal funds rate. A bank could borrow at the discount window if it was financially sound and willing to pay a relatively high interest rate.

3.1.3 More frequent changes in discount rates during recessions

As an important monetary policy instrument, discount rate was used much more frequently in recessions. The history of discount rate data shows that usually the discount rate is lowered as soon as the recession starts. As the recession gets deeper and deeper, the discount rate is lowered again and again. Once the recession is close to an end, the discount rate is raised accordingly.

3.1.4 A unique problem in the discount window borrowing and the creation of TAF

If the discount rate is higher than the federal funds rate, then borrowing from the Federal Reserve is more expensive than borrowing at the federal funds market, which is fine during normal times. However, during the recent financial crisis, although the discount rate was cut 12 times, it was never below the federal funds rate, which means the discount window could no longer ease the liquidity problem during the time of crisis. This is a unique problem that occurred in the recent crisis, because never in the U.S. history was the discount rate higher than the federal funds rate during any recessions.

Usually before 2003, the discount rate was much lower than the federal funds rate during recessions, compared to normal times.

It is quite obvious that the Fed was facing a unique problem in the discount window borrowing during the "Great Recession". Partly in response to this problem, the Federal Reserve created TAF borrowing and other borrowing facilities to allow banks borrow money from other channels rather than the discount window. As it was well known, banks were not willing to borrow from the discount window anyway, because it may signal the bank's poor condition and the possibility of insolvency. Just as Cecchetti (2008) said in his paper, "Realizing that their traditional instruments were inadequate for responding to the crisis that began on August 2007, Federal Reserve Officials improvised." The Fed started to implement a variety of changes to make sure that the banking institutions which needed the most funds can get the liquidity. For instance, the Federal Reserve initiated TAF borrowing.

3.1.5 The relationship between a recession and a financial crisis

In the United States, it is the National Bureau of Economic Research (NBER) that defines the beginning and ending dates of the U.S. recessions. The NBER defines a recession if there is a significant decline in GDP, real income, employment, industrial production, and wholesale-retail sales.[7] The recent sub-prime mortgage crisis is usually called a "financial crisis", which is also a recession. One might ask what the difference between financial crisis and recession is. A financial crisis must be a recession, but a recession is not necessarily a financial crisis. We consider a recession a "financial crisis", if some financial institutions or assets suddenly lose a large part of their value. The recent sub-prime mortgage crisis is considered as a "financial crisis", since it associated with stock market crash, bankruptcies of large investment banks, and banking panics. Many recessions are financial crises, since usually those phenomena occur at the same time.

3.1.6 Another breaking point: 1960s

Before the early 1960s, the Federal Reserve normally did not explain why they changed the discount rate. They just simply changed it with no any further interpretation of policy indication. After the early 1960s, the Federal Reserve announced the reasons for the change of the discount rate so that the public is able to better understand the movements of the Fed and make a better decision. This is an indication that the Federal Reserve indeed improved its transparency.

3.1.7 Classification of discount rate changes

Discount rate changes can be considered either technical or nontechnical according to Thornton (1982): if the discount rate is simply adjusted to keep certain level of difference with market rates such as the federal funds rate, then it is a technical change. Otherwise, it is a non-technical change. Later, some other researchers such as Cook and Hahn (1988) did a more complicated classification. They classified discount rate changes into three types. "Type 1" is technical changes; "Type 3" is non-technical changes, meaning that the Federal Reserve changed the discount rate to deal with the inflation,

[7] See Wikipedia for more details about the definition of "recession".

economic growth, growth rate of money, and some other macroeconomic variables; "Type2" is the mixture of "Type 1" and " Type 3".

This paper follows Thornton's (1982) straightforward way of classification: discount rate changes are divided into technical, ΔDR_T, or non-technical, ΔDR_{NT}, depending on whether the discount rate changes were made purely to keep the discount rate a certain level of difference with market rates or otherwise.

3.2 Motivation

Discount rate changes were much more frequent in the recession times compared to normal times. Thus it is worth exploring the discount rate changes and their effects on market rates during the recessions. From 1996 to 2011[8], the discount rate has been resettled 52 times, among which, only two times were technical changes, and the rest were non-technical changes. Generally speaking, when the economy was in a good shape, the Fed will increase the discount rate to fight inflation. However, If the economy was facing a downturn, the Fed will reduce the discount rate to accommodate the unfavorable situation. During the years 1996 through 2011, there have been two U.S. recessions, early 2000s recession and the "Great Recession" respectively. The early 2000s recession covered the period from March, 2001 to November, 2001, totalling eight months. At that time, Green Span was in charge of the Federal Reserve, the discount rate was reduced 7 times in those short 8 months, and this frequency is very high. The "Great recession", also known as sub-prime mortgage crisis, started in December, 2007 and ended in June 2009, totalling one year and six months, which occurred when the Federal Reserve was under the charge of Bernanke. The discount rate was cut 12 times during this period. In conclusion, among 52 changes during the years 1996 through 2011, 19 occurred during

[8] The "Press Release" of the Federal Reserve can be found back to 1996, which explained why the the Fed changed discount rate. According to the announcement, this paper further classified the discount rate changes into technical changes or non-technical changes.

the recession time. There were 16 years or 192 months in total, during which 26 months were in recession. That is, 13.5 percent of the time was in recession and 36.5 percent of the discount rate changes occurred during the recessions. Therefore, the discount rate changes were more frequent during the recessions compared to normal times. Many existing literatures have studied the discount rate, but no literature has tried to explore the discount rate changes during different U.S. recessions. In fact, it is important to understand the market's response patterns to discount rate changes in recessions, because it will help the Fed to make a more efficient monetary policy during that period of time. This paper will explore the discount rate changes and their impacts on market rates for recent U.S. recessions.

3. 3 Literature Review

Many researchers found that the market rates often respond to the non-technical discount rate changes rather than technical discount rate changes. Batten and Thornton (1983) found that announcements of non-technical discount rate changes have significant impact on the dollar's exchange rate. Thornton (1994) investigated why the market rates responded to non-technical discount rate changes. His finding contradicts Cook and Hahn's (1988) hypothesis that Treasury bill rates respond to discount rate changes simply because it signals the changes in the federal funds rate. Cook and Hahn (1988) found evidence that announcements of the discount rate changes signal the changes in the federal funds rate and hence had a significant effect on Treasury bill rates. Thornton (1998) found that the discount rate changes do not signal the changes in monetary policy. The announcement effect is different mainly depending on the information that people believed contained in those announcements. He also pointed out that the direct effect on the markets rates is near to zero. Smirlock and Yawiz (1985) found that markets do not respond to the technical discount rate changes and only react to the discount rate changes when people believed that there is a shift in the monetary policy. This finding is consistent with Thornton's findings (1998). The "markets" that Smirlock and Yawiz checked are stock returns and bond rates with different maturities. Goodfriend's (1991) evidence showed the Federal Reserve control the short-term interest rates by using the discount rate often. Chen, Mohan and Steiner (1999) found that stock market returns respond to the non-technical announcements in discount rate changes significantly.

Thornton (1996) explores the discount rate policies of five Federal Reserve chairmen: Martin, Burns, Miller, Volcker and Greenspan. He checked the market responses to discount rate changes under those five chairmen respectively and found Burns and Volcker's discount rate policies were the most effective and Miller's the least effective. The reason for this different response is that Burns and Volcker provided the market with more complete information when they changed the discount rate than other chairmen. This conclusion is consistent with another Thornton's paper (1998), which suggested that market response varied to the change of the discount rate over time, mainly depending on the information content contained in the announcements of the discount rate changes.

This paper will study the sub-prime mortgage crisis and the early 2000s U.S. recession. Because the discount rate policy is not the same under different Federal Reserve chairmen suggested by Thornton (1996), this paper divided recessions based on the terms of different chairmen. When Greenspan became chairman, he dealt with the early 2000s recession. The "Great Recession" occurred as Bernanke took charge of the Federal Reserve one year later.

3.4 The Data and Model

The data on interest rates are daily (business day only) from 1996 to 2010. The change in the discount rate is the percentage change in the discount rate on the day that a discount rate change was announced. The market interest rates are 3-month Treasury bill rates, 3-month mortgage repo rates, 3-month agency repo rates and 3-month government repo rates.

This paper follows Thornton's (1982) straightforward way of classification: discount rate changes are divided into technical, ΔDR_T, or non-technical, ΔDR_{NT}, depending on whether the discount rate changes were made purely to keep the discount rate a certain level of difference with market rates or otherwise.

To test the hypothesis of whether the market responses to the discount rate changes were significantly different during the period of different recessions, this paper will apply Thorton's model (1998):

$$(1) \quad \Delta i_t = \alpha + \beta(L)\Delta i_{t-1} + \delta(L)\Delta FR_t + \mu_{NT}\Delta DR_{NT} + \mu_T \Delta DR_T + \varepsilon_t$$

Δi is the percentage change in 3-month Treasury bill rates or 3-month repo rates. Equation (1) represents that the change in market rates may depend on the change in previous market rates, the change in both current and lagged federal funds rates, the technical change in the discount rate and the nontechnical change in the discount rate. All of the changes here are percentage changes.

$\beta(L)$ and $\delta(L)$ are in the lag forms.

We can compare the sign and the magnitude of the estimated coefficients for different U.S. recessions in general, and then further check these coefficients under different chairmen.

3.5 The Responses Results of 3-month Treasury bill rates

3.5.1 Result 1 (1996-2010)

Firstly, this paper ran the regression on the following equation over the period from 1996 to 2010. Since among 52 changes in the discount rate, only two of which are technical changes, occurred in 2003 and 2010 respectively, I combined all the discount rate changes together as non-technical changes for simplicity. Equation (1) becomes equation (2):

(2) $\Delta i_t = \alpha + \beta(L)\Delta i_{t-1} + \delta(L)\Delta FR_t + \mu_{NT}\Delta DR + \varepsilon_t$

The dependent variable is the percentage change in the 3-month Treasury bill rate. The independent variables are the percentage change in the lagged 3-month Treasury bill rate, both current and lagged federal funds rates, and the discount rate. This paper found that there are 5 lags in the 3-month Treasury bill rate, which indicates that the change of the 3 month Treasury bill rate correlates to the the change of the 3-month Treasury bill rate, up to 5 business days before. Moreover, this paper found coefficients on both discount rate changes and changes in the federal funds rate are not significantly different from zero.

3.5.2 Result 2 (Early 2000s recession: March, 2001 to November, 2001)

Because from the first result, this paper found evidence that the coefficient on the change in the federal funds rate is not significantly different from zero, so the term of the percentage change in federal funds rate can be ignored. Furthermore, there is no technical change in the discount rate during this period of time. Equation (1) now becomes equation (3):

(3) $\Delta i_t = \alpha + \beta(L)\Delta i_{t-1} + \mu_{NT}\Delta DR_{NT} + \varepsilon_t$

This paper found that the 3-month Treasury bill rate moves the same direction with the discount rate.

The coefficient on the discount rate is significantly different from zero.

3.5.3 Result 3 (Great Recession: December, 2007 - June, 2009)

Coefficients on both discount rate and federal funds rate change are not significantly different from zero. It might have something to do with the TAF borrowing, or the new method of establishing the discount rate. Since 2003, there is a new method of establishing the discount rate, which set the discount rate 100 basis above the federal funds rate, which made the discount rate higher than the federal funds rate. In other words, the discount window borrowing lost its functions during the recent financial crisis. Hence, the Federal Reserve created TAF borrowing and other borrowing facilities to accommodate the recent financial crisis. This helps explain the fact that market rates were not sensitive to the discount rate changes during the "Great Recession".

That the coefficient on the discount rate is not significantly different from zero indicates that the change in the discount rate has no significant impact on the change in the 3-month Treasury bill rate.

Since there are no technical changes in this recession either, the equation (1) becomes equation (4) :

$$(4) \quad \Delta i_t = \alpha + \beta(L)\Delta i_{t-1} + \delta(L)\Delta FR_t + \mu_{NT}\Delta DR_{NT} + \varepsilon_t$$

This paper also tried to run regression on equation (5):

$$(5) \quad \Delta i_t = \alpha + \beta(L)\Delta i_{t-1} + \mu_{NT}\Delta DR_{NT} + \varepsilon_t$$

Removing the term of the federal funds rate in equation (5), the coefficient on the change in the discount rate is not significantly different from zero either.

3.6 The Response Results of 3-month repo rates

From Chapter 2, we know that the 3-month repo rate is one of the important market rates for forecasting monetary policy. Therefore, this paper tests the 3-month repo rates response pattern to discount rate changes. Besides 3-month Treasury bill rates, this chapter will test how three types of 3-month repo rates responded to discount rate changes during the two recent U.S. recessions.

3.6.1 The responses of 3-month government repo rates

Using different estimation equations (See tables 3.11 through 3.14), this paper shows that during the early 2000s recession, 3-month government repo rates did not respond to either federal funds rates or discount rate changes significantly at both 1% and 5% significance levels.

During the "Great Recession," 3-month government repo rates did not respond to either discount rate changes or changes in federal funds rates significantly at both 1% and 5% significance levels (See tables 3.15 through 3.18). However, the significance levels of the coefficients of both federal funds rates and discount rate changes were higher during the early 2000s recession than during the "Great Recession." This may suggest that the 3-month government repo rates are less responsive to both discount rate changes and federal funds rates during the "Great Recession" than during the early 2000s recession.

3.6.2 The responses of 3-month agency repo rates

During both early 2000 recession and the "Great Recession," 3-month agency repo rates did not respond to either discount rate changes or federal funds rates at both 1% and 5% significance levels.

3.6.3 The responses of 3-month mortgage repo rates

During early 2000 recession, 3-month mortgage repo rates responded only to discount rate changes at a 5% significance level. At 1% significance level, 3-month mortgage repo rates did not respond to either discount rate changes or federal funds rates.

During the "Great Recession," 3-month mortgage repo rates did not respond to either discount rate changes or federal funds rates significantly at both 1% and 5% significance levels.

3.6.4 The summarization of the responses results of 3-month repo rates

At a 1% significance level, 3-month government, agency and government repo rates did not respond to either discount rate changes or federal funds rates significantly during both early 2000s recession and the "Great Recession." This provided evidence that the response patterns of 3-month repo rates to discount rate changes were quite similar. From the second chapter, we know that the forecasting ability of three types of 3-month repo rates for monetary policy are also similar. This provided evidence for future researchers that the three types of 3-month repo rates have similar characteristics.

At a 5% significance level, both 3-month government and agency repo rates did not respond to either discount rate changes or federal funds rates significantly during both early 2000s recession and the "Great Recession." However, 3-month mortgage repo rates responded to discount rate changes during early 2000s recession and did not respond to discount rate changes during the "Great Recession." To be more specific, 3-month mortgage repo rates moved the same direction with discount rate changes during the early 2000s recession and were not responsive to discount rate changes during the "Great Recession." This is consistent with the response patterns of 3-month Treasury bill rates. This result further provids evidence that the market rates tended to be less responsive to discount rate changes during the "Great Recession." It is due to the fact that the discount window borrowing has lost its function during the "Great Recession."

3.7 Conclusions

3.7.1 The responses of market rates to the discount rate changes during U.S. recessions

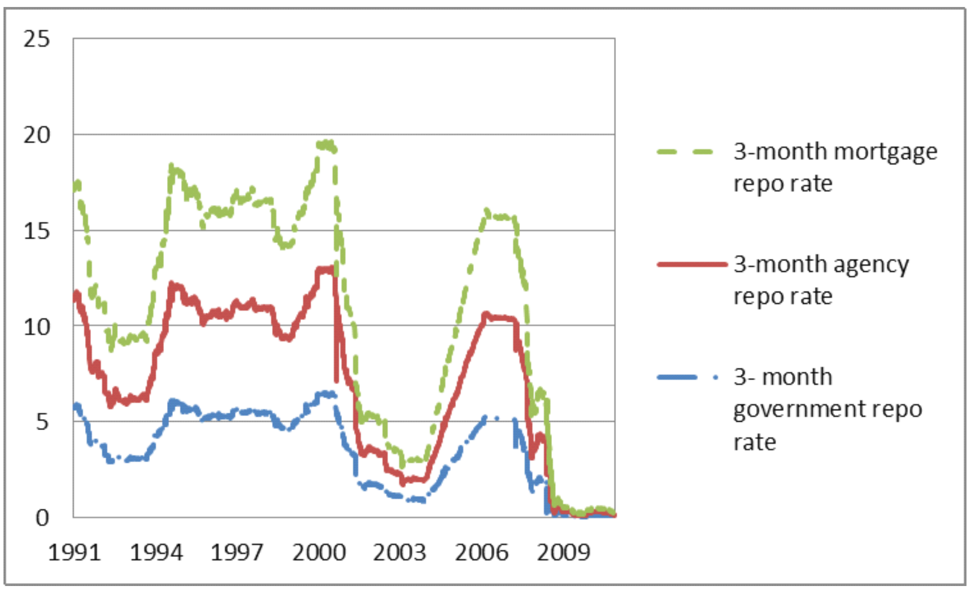
Firstly, this paper shows that the responses of 3-month Treasury bill rates to the discount rate changes varied during the recent two recessions. During the early 2000s recession, the 3-month Treasury bill rate responded significantly to the discount rate changes. More specifically, the 3-month Treasury bill rate moved the same direction as the discount rate. However, the reaction of the 3-month Treasury bill rate to the discount rate changes was not significant during the "Great Recession." Why are the responses of the 3-month Treasury bill rate to the discount rate changes different between the two recessions? One of the reasons could be that the discount window borrowing has lost its function during the "Great Recession," since the discount rates were above the federal funds rates during the recent recession. Banking sectors borrowed funds from other channels instead, for instance, TAF facilities. In this case, market rates were no longer sensitive to the discount rate changes. To sum up, the different responses of market rates to the discount rate changes are due to the various economic and policy circumstances that the market was facing. This conclusion is consistent with Thornton's finding (1998). He found evidence that the announcement effect of the discount rate changes varied because of the information that people believed contained in the announcement.

Secondly, this paper showed that at a 1% significance level, 3-month government, agency and government repo rates did not respond to either discount rate changes or federal funds rates significantly during both early 2000s recession and "Great Recession." At a 5% significance level, both 3-month government and agency repo rates did not respond to either discount rate changes or federal funds rates significantly during both early 2000s recession and "Great Recession." However, 3-month mortgage repo rates responded to discount rate changes during early 2000s recession and did not respond to discount rate changes during "Great Recession." To be more specific, 3-month mortgage repo rates moved the same direction with discount rate changes during early 2000s recession and were not responsive to discount rate changes during the "Great Recession." This is consistent with the response patterns of 3-month Treasury bill rates. This result further provided evidence that the market rates tended to be less responsive to discount rate changes during the "Great Recession." It is due to the fact that the discount window borrowing has lost its function during the "Great Recession."

Last but not least, this paper supports Thornton's (1994) finding, which contradicts Cook and Hahn's (1988) Hypothesis that the Treasury bill rates respond to discount rate changes simply because it signals the changes in the federal funds rate. The estimation results of this paper show that both the 3-month Treasury bill rate and 3-month repo rates did not significantly respond to the changes in federal funds rates at both 1% and 5% significance levels during both recent recessions.

3.7.2 Some findings on the Characteristics of three types of 3-month repo rates

First of all, three types of 3-month repo rates have similar trends over the recent two decades. In other words, they move together at the same time.



Notes: The above figure used a stacked line chart to show the trend of the three types of repo rates. It is very obvious that they tend to move together. The 3-month mortgage repo rate has the highest value of all the three types of repo rates, because a mortgage repurchase agreement is more risky than the other two repurchase agreements. Both government and agency repurchase agreements enjoy protections from U.S. Government.

Secondly, when using three types of 3-month repo rates as long term rates respectively, expectation theory is found to perform extremely well in all the three cases.

Thirdly, three types of 3-month repo rates have very similar forecasting ability for federal funds rates.

Last but not least, three types of 3-month repo rates were not responsive to discount rate changes during the recent U.S. recessions at a 1% significance level.

To sum up, three types of 3-month repo rates have similar characteristics. They have similar moving trends over time, similar performances in expectation theory, similar forecasting abilities for future federal funds rates, and similar response patterns to discount rate changes.

Table 3.1: Recent U.S. recessions and corresponding chairmen

Chairman	Term	U.S. Recession
Alan Greenspan	August 11, 1987 - Jannuary 31, 2006	Early 1990s recession Early 2000s recession
Ben Bernanke	February 1, 2006 - present	Great Recession

Table 3.2: Classification of discount rate changes (1996-2011)

(Information was collected from the website of Board of Governors of the Federal Reserve System, and was edited and consolidated by myself. According to the reasons for the changes of the discount rates that the Federal Reserve released, I classified the discount rate changes into either technical changes or non-technical changes.) From 1996 to 2011, the discount rate has been resettled 52 times, among which, only two times were technical changes. The rest were non-technical changes. Generally speaking, when the economy was in a good shape, the Federal Reserve would increase the discount rate to fight inflation. However, if the economy was facing a downturn, the Federal Reserve would reduce the discount rate to accommodate the poor situation. During the years 1996 through 2011, there has been two U.S. recessions, early 2000s recession and the "Great Recession" respectively. The early 2000s recession covered the period from March, 2001 to November, 2001, totalling eight months. At that time, when Greenspan was in charge of the Federal Reserve, the discount rate was reduced 7 times in those short 8 months, and the frequency was very high. The "Great Recession", also known as sub-prime mortgage crisis, started in December, 2007 and ended in June 2009, totalling one year and six months, which happened when the Federal Reserve was under the charge of Bernanke. The discount rate was cut 12 times during this period. Among 52 changes, 19 occurred during the recession time. From 1996 to 2011, totalling 16 years or 192 months, 26 months were in recession. 13.5 percent of the time was in recession. 36.5 percent of the discount rate changes occurred during the recessions. In conclusion, discount rate changes were much more frequent in the recession times compared to normal times.

Date of Press Release	Decision	Main Reasons	Define the change
April 13, 2010	Increase the discount rate from 0.5 percent to 0.75 percent discussed on February 17, 2010.	This is the first step for the Fed to widen the spread between the discount rate and the federal funds rate.	Technical change
January 13, 2009	Decrease the discount rate from 1.25 percent to 0.5 percent on December 16, 2008.	Financial crisis became severe.	Non-technical change
November 25, 2008	Decrease the discount rate from 1.75 percent to 1.25 percent on October 29, 2008. Decrease the discount rate from 2.25 percent to 1.75 percent approved on October 7, 2008.	Tight credit conditions in financial market and weakness in the labor market were significant.	Non-technical change
May 27, 2008	Decrease the discount rate from 2.5 percent to 2.25 percent approved on April 30, 2008.	Fed wanted to help the economy out of the financial crisis.	Non-technical change
April 15, 2008	Decrease the discount rate from 3.25 percent to 2.5 percent approved on March 18, 2008. Decrease the discount rate from 3.5 percent to 3.25 percent approved on March 16, 2008.	There is a further deterioration in financial conditions and the economy.	Non-technical Change (both)
February 26, 2008	Decrease the discount rate from 4.75 percent to 4 percent approved on January 21, 2008.	The economic activity is weak and downside risks increase.	Non-technical Change (both)

	Decrease the discount rate from 4 percent to 3.5 percent approved on January 30, 2008.		
January 8, 2008	Decrease the discount rate from 5 percent to 4.75 percent approved on December 11, 2007.	The downside risks to economic growth increased and financial market conditions became worse.	Non-technical change
November 27, 2007	Decrease the discount rate from 5.25 percent to 5 percent approved on October 31, 2007.	Housing sector had gone worse.	Non-technical change
October 16, 2007	Decrease the discount rate from 6.25 percent to 5.75 percent approved on August 16, 2007. Decrease the discount rate from 5.75 percent to 5.25 percent approved on September 18, 2007.	Credit became tight and housing sector had been intensified.	Non-technical Change (both)
July 25, 2006	Increase the discount rate from 6 percent to 6.25 percent approved on June 29, 2006.	Inflation pressures occurred.	Non-technical change
June 6, 2006	Increase the discount rate from 5.75 percent to 6 percent approved on May 10, 2006.	Economy was in good shape except for inflation pressure.	Non-technical change
April 25, 2006	Increase the discount rate from 5.5 percent to 5.75 percent approved on March 28, 2006.	Contained inflation.	Non-technical change

February 28, 2006	Increase the discount rate from 5.25 percent to 5.5 percent approved on January 31, 2006.	Inflation pressure.	Non-technical change
January 10, 2006	Increase the discount rate from 5 percent to 5.25 percent approved on December 13, 2005.	Inflation risk and high level of energy price.	Non-technical change
November 29, 2005	Increase the discount rate from 4.75 percent to 5 percent approved on November 1, 2005.	High energy price was added to inflation pressure.	Non-technical change
October 18, 2005	Increase the discount rate from 4.5 percent to 4.75 percent approved on September 20, 2005.	Good economic outlook called for removal of the monetary policy accommodation.	Non-technical change
September 6, 2005	Increase the discount rate from 4.25 percent to 4.5 percent approved on August 9, 2005.	Business conditions were improving nationwide.	Non-technical change

July 28, 2005	Increase the discount rate from 4 percent to 4.25 percent approved on June 30, 2005.	The economy was as good as expected, with modest inflation pressure.	Non-technical change
May 31, 2005	Increase the discount rate from 3.75 percent to 4 percent approved on May 3, 2005.	The gradual removal of accommodative monetary policy was appropriate	Non-technical change
April 19, 2005	Increase the discount rate from 3.5 percent to 3.75 percent approved on March 22, 2005.	Labor market and investment improved with signs of inflation.	Non-technical change
March 2, 2005	Increase the discount rate from 3.25 percent to 3.5 percent approved on February 2, 2005.	Positive near-term outlook for the economy with contained inflation.	Non-technical change
January 11, 2005	Increase in the discount rate from 3 percent to 3.25 percent approved on December 14, 2004.	Economic growth was solid.	Non-technical change
December 21, 2004	Increase in the discount rate from 2.75 percent to 3 percent approved on November 10, 2004.	The economy continued to expand and it was time to withdraw monetary stimulus gradually.	Non-technical change
November 18, 2004	Increase the discount rate from 2.5 percent to 2.75 percent approved on September 21, 2004.	The economic outlook was favorable.	Non-technical change

September 30, 2004	Increase the discount rate from 2.25 percent to 2.5 percent approved on August 10, 2004.	CPI showed an increase in inflation.	Non-technical change
August 19, 2004	Increase the discount rate from 2 percent to 2.25 percent approved on June 30, 2004.	The economy was growing at a solid pace and no longer needed monetary accommodation.	Non-technical change
August 21, 2003	Decrease the discount rate from 2.25 percent to 2 percent approved on June 25, 2003.	Expectations for growth were improving, but it was too early to be optimistic.	Non-technical change
March 28, 2003	Twelve Reserve Banks approved new formula for calculating discount rate on January 6, 2003.	100 basis points above the federal funds rate	Technical change
December 23, 2002	Decrease the discount rate from 1.25 percent to 0.75 percent approved on November 6, 2002.	Consumer confidence weakened related to terrorism.	Non-technical change
February 8, 2002	Decrease the discount rate from 1.5 percent to 1.25 percent approved on December 11, 2001.	The economic outlook remained uncertain.	Non-technical change
December 28, 2001	Decrease the discount rate from 2 percent to 1.5 percent approved on November 6, 2001.	Both business and consumer confidence weakened.	Non-technical change
November 16, 2001	Decrease the discount rate from 2.5 percent to 2 percent approved on October 2, 2001.	September 11 event effect.	Non-technical change

October 26, 2001	Decrease the discount rate from 3 percent to 2.5 percent approved on September 17, 2001.	Employment, production, and business spending were weak. After September 11, consumer confidence dropped further.	Non-technical change
October 26, 2001	Decrease the discount rate from 3.25 percent to 3 percent approved on August 21, 2001.	No significant signs of economic recovery.	Non-technical change
October 26, 2001	Decrease the discount rate from 3.5 percent to 3.25 percent approved on June 27, 2001.	There had been an continued decline in the manufacturing.	Non-technical change
May 15, 2001	Decrease from 4 percent to 3.25 percent on May 15, 2001.	The economy was still weak in the near future.	Non-technical change
April 19, 2001	Decrease the discount rate from 4.5 percent to 4 percent on April 19, 2001.	The economy was still weak in the near future.	Non-technical change
March 20, 2001	Decrease the discount rate from 5 percent to 4.5 percent on March 20, 2001.	Investment spending was weak.	Non-technical change

January 31, 2001	Decrease the discount rate from 5.5 percent to 5 percent on January 31, 2001.	Consumer and business confidence had been weakened further due to the high energy cost, which lower the purchasing power and business profit.	Non-technical change
January 4, 2001	Decrease the discount rate from 6 percent to 5.5 percent on January 4, 2001.	Consumer and business confidence had been weakened further due to the high energy cost, which lower the purchasing power and business profit	Non-technical change
May 17, 2000	Increasing discount rate at those banks from 5.5 percent to 6 percent on May 18, 2000.	Inflation pressure.	Non-technical change
March 21, 2000	Increase the discount rate from 5.25 to 5.5 percent on March 21, 2000.	Increased demand exceeded potential supply. Inflation pressure occurred.	Non-technical change
February 2, 2000	Increase the discount rate from 5 percent to 5.25 percent on February 2, 2000.	Increased demand exceeded potential supply. Inflation pressure occurred.	Non-technical change
November 16, 1999	Increase in the discount rate from 4.75 percent to 5 percent on November 16, 1999.	Inflation pressure.	Non-technical change

August 24, 1999	Increase the discount rate from 4.5 percent to 4.75 percent on August 24, 1999.	The overall economic conditions were good, so it was time to remove monetary accommodation.	Non-technical change
November 17, 1998	Decrease the discount rate from 4.75 percent to 4.5 percent on November 17, 1998.	Although conditions in financial markets have gone well since October, unusual strains remain.	Non-technical change
October 15, 1998	Decrease the discount rate from 5 percent to 4.75 percent on October 15, 1998.	The conditions in financial markets were bad.	Non-technical change
January 31, 1996	Decrease the discount rate from 5.25 percent to 5 percent on January 31, 1996.	Moderating economic expansion in recent months has reduced potential inflationary pressures.	Non-technical change

Table 3.3: Three month Treasury bill rate with one lag (equation 2)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
cfr	-.0008239	.0004507	0.068	-.0017075	.0000598
ctb3l1	.8261811	.009318	0.000	.8079122	.84445
cdisr	.0001602	.000849	0.850	-.0015044	.0018248
_cons	-.087911	.0057384	0.000	-.0991616	-.0766603

Table 3.4: Three month Treasury bill rate with two lags (equation 2)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	.5119664*	.0153012	0.000	.4819669	.5419658
ctb3l2	.3806851*	.0153033	0.000	.3506815	.4106887
cfr	-.0002791	.0004183	0.505	-.0010992	.000541
cdisr	.0001119	.0007869	0.887	-.0014309	.0016546
_cons	-.0539694*	.0054905	0.000	-.064734	-.0432047

Table 3.5: Three month Treasury bill rate with four lags (equation 2)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	.310697*	.0154823	0.000	.2803425	.3410515
ctb3l2	.1539418*	.0161932	0.000	.1221935	.1856901
ctb3l3	.1278207*	.0161796	0.000	.0960991	.1595422
ctb3l4	.3579709*	.0154738	0.000	.3276331	.3883088
cdisr	.0000706	.000709	0.921	-.0013193	.0014606
cfr	-.000201	.000377	0.594	-.0009402	.0005382
_cons	-.0242162*	.0050547	0.000	-.0341263	-.0143061

Table 3.6: Three month Treasury bill rate with five lags (equation 2)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	.2806045*	.0165544	0.000	.248148	.313061
ctb3l2	.1437165*	.0162691	0.000	.1118194	.1756136
ctb3l3	.1149804*	.0163289	0.000	.082966	.1469949
ctb3l4	.3321171*	.0162601	0.000	.3002377	.3639966
ctb3l5	.0831356*	.016549	0.000	.0506897	.1155814
cdisr	.0000723	.0007067	0.918	-.0013132	.0014578
cfr	-.0002139	.0003758	0.569	-.0009507	.000523
_cons	-.022061*	.0050567	0.000	-.0319751	-.0121469

Table 3.7: Three month Treasury bill rate with six lags (equation 2)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	.2579442*	.0162627	0.000	.2260596	.2898288
ctb3l2	.10663*	.0168428	0.000	.0736081	.1396519
ctb3l3	.0381887*	.0169298	0.024	.0049961	.0713812
ctb3l4	.2991155*	.0161399	0.000	.2674718	.3307593
ctb3l5	.0354097*	.0169365	0.037	.002204	.0686153
ctb3l6	.0253706	.0169021	0.133	-.0077675	.0585088
cfr	-.0001272	.0003671	0.729	-.000847	.0005927
cdisr	.0000705	.0006902	0.919	-.0012827	.0014238
_cons	-.0153363*	.0049692	0.002	-.0250789	-.0055938

Table 3.8: Result 2 (equation 3)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	(omitted)				
ctb3l2	1*	4.87e-08	0.000	.9999999	1
ctb3l3	(omitted)				
ctb3l4	(omitted)				
ctb3l5	(omitted)				
cdisr	7.24e-10*	2.65e-10	0.007	2.00e-10	1.25e-09
_cons	.0005728*	1.88e-08	0.000	.0005727	.0005728

note: ctb3l1 omitted because of collinearity

note: ctb3l3 omitted because of collinearity
note: ctb3l4 omitted because of collinearity
note: ctb3l5 omitted because of collinearity

Table 3.9: Result 3 (equation 4)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	(omitted)				
ctb3l2	1*	3.12e-08	0.000	.9999999	1
ctb3l3	(omitted)				
ctb3l4	(omitted)				
ctb3l5	(omitted)				
cdisr	-1.86e-10	3.79e-10	0.624	-9.31e-10	5.59e-10
cfr	-1.03e-10	1.04e-10	0.320	-3.07e-10	1.00e-10
_cons	.0005728*	2.84e-08	0.000	.0005727	.0005728

note: ctb3l1 omitted because of collinearity
note: ctb3l3 omitted because of collinearity
note: ctb3l4 omitted because of collinearity
note: ctb3l5 omitted because of collinearity

Table 3.10: Result 3 (equation 5)

ctb3	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
ctb3l1	(omitted)				
ctb3l2	1*	3.12e-08	0.000	.9999999	1
ctb3l3	(omitted)				
ctb3l4	(omitted)				
ctb3l5	(omitted)				
cdisr	-1.83e-10	3.79e-10	0.629	-9.28e-10	5.62e-10
_cons	.0005728*	2.84e-08	0.000	.0005727	.0005728

note: ctb3l1 omitted because of collinearity
note: ctb3l3 omitted because of collinearity
note: ctb3l4 omitted because of collinearity
note: ctb3l5 omitted because of collinearity

Table 3.11 Test 1: The response of 3-month government repo rates to discount rate changes (early 2000s recession)

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.2015769	.0714822	0.005	-.3425728	-.060581
grpl2	-.1355546	.0711293	0.058	-.2758545	.0047452
cdisr	.0400796	.0683406	0.558	-.0947196	.1748788
cfr	-.0234814	.0225956	0.300	-.0680504	.0210877
_cons	-.6709759	.2139097	0.002	-1.092905	-.2490471

Table 3.12 Test 2: The response of 3-month government repo rates to discount rate changes (early 2000s recession)

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.1768604	.0707759	0.013	-.3164586	-.0372622
cfr	-.0259484	.0227126	0.255	-.0707467	.0188499
cdisr	.0452273	.0687536	0.511	-.0903822	.1808367
_cons	-.588219	.2108863	0.006	-1.00417	-.1722677

Table 3.13 Test 3: The response of 3-month government repo rates to discount rate changes (early 2000s recession)

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.2039575	.0714603	0.005	-.3449056	-.0630093
grpl2	-.1397893	.0710273	0.050	-.2798833	.0003046
cdisr	.0360635	.0682454	0.598	-.0985436	.1706706
_cons	-.6736794	.2139384	0.002	-1.095651	-.2517081

Table 3.14 Test 4: The response of 3-month government repo rates to discount rate changes (early 2000s recession)

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.1768604	.0707759	0.013	-.3164586	-.0372622
cfr	-.0259484	.0227126	0.255	-.0707467	.0188499
cdisr	.0452273	.0687536	0.511	-.0903822	.1808367
_cons	-.588219	.2108863	0.006	-1.00417	-.1722677

Table 3.15 Test 1: The response of 3-month government repo rates to discount rate changes ("Great Recession")

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.1476465	.0497475	0.003	-.2454427	-.0498502
grpl2	-.0107008	.050221	0.831	-.109428	.0880264
grpl3	-.06108	.0501838	0.224	-.1597339	.0375739
grpl4	-.0389005	.0502771	0.440	-.1377379	.0599369
grpl5	.013069	.0497225	0.793	-.084678	.1108161
cfr	-.0612532	.1046648	0.559	-.2670089	.1445025
cdisr	.1883457	.3893065	0.629	-.5769738	.9536651
_cons	1.546673	1.437916	0.283	-1.280058	4.373404

Table 3.16 Test 2: The response of 3-month government repo rates to discount rate changes ("Great Recession")

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.1453917	.0489904	0.003	-.2416968	-.0490866
cfr	-.0579825	.10434	0.579	-.2630935	.1471286
cdisr	.1833275	.3873337	0.636	-.5780913	.9447463
_cons	1.426264	1.427485	0.318	-1.37988	4.232408

Table 3.17 Test 3: The response of 3-month government repo rates to discount rate changes ("Great Recession")

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.1458307	.0495752	0.003	-.243286	-.0483753
grpl2	-.0030231	.0495471	0.951	-.1004233	.0943771
cfr	-.0578666	.1044849	0.580	-.263264	.1475308
cdisr	.1836013	.3878334	0.636	-.5788055	.9460081
_cons	1.430413	1.430848	0.318	-1.382362	4.243188

Table 3.18 Test 4: The response of 3-month government repo rates to discount rate changes ("Great Recession")

grp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
grpl1	-.1455727	.0489479	0.003	-.2417935	-.0493518
cdisr	.1872495	.386942	0.629	-.5733938	.9478928
_cons	1.414239	1.426115	0.322	-1.38919	4.217669

Table 3.19 Test 1: The response of 3-month agency repo rates to discount rate changes (early 2000s recession)

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.1025694	.0725118	0.159	-.2455961	.0404573
arpl2	-.0024373	.0729517	0.973	-.1463319	.1414572
cfr	-.007265	.0221868	0.744	-.0510276	.0364977
cdisr	-.0216051	.0678359	0.750	-.1554089	.1121987
_cons	-.5689471	.2097771	0.007	-.9827245	-.1551697

Table 3.20 Test 2: The response of 3-month agency repo rates to discount rate changes (early 2000s recession)

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.1023424	.0720046	0.157	-.2443641	.0396793
cfr	-.0072905	.0221159	0.742	-.0509119	.0363309
cdisr	-.0213135	.0670968	0.751	-.1536551	.1110281
_cons	-.5674774	.2045785	0.006	-.9709873	-.1639674

Table 3.21 Test 3: The response of 3-month agency repo rates to discount rate changes (early 2000s recession)

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.1025267	.0723429	0.158	-.2452156	.0401621
arpl2	-.0032593	.0727388	0.964	-.1467291	.1402105
cdisr	-.0228837	.0675658	0.735	-.1561503	.1103829
_cons	-.569155	.2092879	0.007	-.9819536	-.1563563

Table 3.22 Test 4: The response of 3-month agency repo rates to discount rate changes (early 2000s recession)

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.1023424	.0720046	0.157	-.2443641	.0396793
cfr	-.0072905	.0221159	0.742	-.0509119	.0363309
cdisr	-.0213135	.0670968	0.751	-.1536551	.1110281
_cons	-.5674774	.2045785	0.006	-.9709873	-.1639674

Table 3.23 Test 5: The response of 3-month agency repo rates to discount rate changes (early 2000s recession)

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
cfr	-.0071318	.022174	0.748	-.0508663	.0366027
cdisr	-.0290446	.0670525	0.665	-.1612944	.1032052
_cons	-.5211485	.2024982	0.011	-.9205421	-.1217549

Table 3.24 Test 6: The response of 3-month agency repo rates to discount rate changes (early 2000s recession)

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.1001265	.0729881	0.172	-.2441075	.0438545
arpl2	-.0019255	.0736781	0.979	-.1472676	.1434165
arpl3	.0175497	.0736834	0.812	-.1278027	.1629022
arpl4	-.0226244	.0732424	0.758	-.167107	.1218583
arpl5	.054783	.0729981	0.454	-.0892175	.1987836
cfr	-.0066622	.0223299	0.766	-.0507116	.0373871
cdisr	-.0277991	.0688965	0.687	-.1637087	.1081104
_cons	-.5456446	.2211427	0.015	-.9818845	-.1094047

Table 3.25 Test 1: The response of 3-month agency repo rates to discount rate changes ("Great Recession")

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.5028742	.0496793	0.000	-.6005365	-.4052119
arpl2	-.2959229	.0551175	0.000	-.4042759	-.1875699
arpl3	-.1624143	.0563531	0.004	-.2731962	-.0516324
arpl4	-.0813604	.0549528	0.140	-.1893895	.0266687
arpl5	-.0321365	.0491841	0.514	-.1288252	.0645522
cfr	-.0398113	.0410281	0.332	-.1204666	.040844
cdisr	-.1221029	.1522449	0.423	-.421394	.1771883
_cons	-.1068515	.5596822	0.849	-1.207105	.9934017

Table 3.26 Test 2: The response of 3-month agency repo rates to discount rate changes ("Great Recession")

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.3836339	.0457761	0.000	-.4736204	-.2936474
cfr	-.0341007	.0422349	0.420	-.1171259	.0489246
cdisr	-.0870958	.156524	0.578	-.3947899	.2205983
_cons	-.0862602	.5764683	0.881	-1.219479	1.046958

Table 3.27 Test 3: The response of 3-month agency repo rates to discount rate changes ("Great Recession")

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.4662309	.0483391	0.000	-.5612564	-.3712054
arpl2	-.2158416	.0478941	0.000	-.3099922	-.121691
cfr	-.0381661	.0412795	0.356	-.1193137	.0429815
cdisr	-.1073132	.1530123	0.483	-.4081062	.1934798
_cons	-.0923585	.5632942	0.870	-1.199688	1.014971

Table 3.28 Test 4: The response of 3-month agency repo rates to discount rate changes ("Great Recession")

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.3816794	.0456926	0.000	-.4715012	-.2918577
cdisr	-.0850245	.1564363	0.587	-.3925441	.222495
_cons	-.0934549	.5761541	0.871	-1.226048	1.039138

Table 3.29 Test 5: The response of 3-month agency repo rates to discount rate changes ("Great Recession")

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.4902726	.0491112	0.000	-.5868151	-.39373
arpl2	-.2696619	.0527909	0.000	-.3734379	-.1658859
arpl3	-.1181446	.0486538	0.016	-.213788	-.0225012
_cons	-.0670295	.5566543	0.904	-1.161298	1.027239

Table 3.30 Test 6: The response of 3-month agency repo rates to discount rate changes ("Great Recession")

arp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
arpl1	-.492894	.0492305	0.000	-.5896724	-.3961155
arpl2	-.2729168	.0528867	0.000	-.3768828	-.1689508
arpl3	-.1205972	.0487219	0.014	-.2163759	-.0248186
cdisr	-.1204637	.1521504	0.429	-.4195646	.1786371
cfr	-.0405921	.0410336	0.323	-.121257	.0400728
_cons	-.1017703	.5597926	0.856	-1.202224	.9986835

Table 3.31 Test 1: The response of 3-month mortgage repo rates to discount rate changes (early 2000s recession)

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.0917864	.0713402	0.200	-.2325023	.0489295
mrpl2	.0159791	.0712856	0.823	-.1246291	.1565873
cfr	-.0054524	.0211391	0.797	-.0471484	.0362436
cdisr	.1565391	.0640209	0.015	.0302604	.2828178
_cons	-.4592702	.2005899	0.023	-.8549262	-.0636142

Table 3.32 Test 2: The response of 3-month mortgage repo rates to discount rate changes (early 2000s recession)

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.0934349	.0707844	0.188	-.2330499	.0461801
cfr	-.0053515	.0210819	0.800	-.0469335	.0362304
cdisr	.1569177	.0638401	0.015	.0309997	.2828356
_cons	-.468113	.1961855	0.018	-.8550686	-.0811574

Table 3.33 Test 3: The response of 3-month mortgage repo rates to discount rate changes (early 2000s recession)

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.0921355	.0711538	0.197	-.232479	.048208
mrpl2	.0155879	.071096	0.827	-.1246416	.1558175
cdisr	.1556534	.0637731	0.016	.0298676	.2814393
_cons	-.4594763	.2001001	0.023	-.8541531	-.0647995

Table 3.34 Test 4: The response of 3-month mortgage repo rates to discount rate changes (early 2000s recession)

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.0934349	.0707844	0.188	-.2330499	.0461801
cfr	-.0053515	.0210819	0.800	-.0469335	.0362304
cdisr	.1569177	.0638401	0.015	.0309997	.2828356
_cons	-.468113	.1961855	0.018	-.8550686	-.0811574

Table 3.35 Test 5: The response of 3-month mortgage repo rates to discount rate changes (early 2000s recession)

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
cdisr	.1616092	.0638635	0.012	.0356491	.2875693
cfr	-.0058211	.0211194	0.783	-.0474757	.0358334
_cons	-.4181375	.1928675	0.031	-.7985363	-.0377388

Table 3.36 Test 6: The response of 3-month mortgage repo rates to discount rate changes (early 2000s recession)

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
cdisr	.1606696	.0636204	0.012	.0351931	.2861462
_cons	-.41795	.1924065	0.031	-.797427	-.038473

Table 3.37 Test 1: The response of 3-month mortgage repo rates to discount rate changes ("Great Recession")

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.1828347	.0495796	0.000	-.2803009	-.0853686
mrpl2	-.0872755	.0502723	0.083	-.1861035	.0115525
mrpl3	-.0311055	.0504466	0.538	-.1302761	.068065
mrpl4	-.0585983	.0502152	0.244	-.1573139	.0401174
mrpl5	-.0940599	.0671058	0.162	-.2259801	.0378604
cfr	-.0267551	.0975689	0.784	-.2185612	.165051
cdisr	-.3766381	.495089	0.447	-1.34991	.5966342
_cons	1.216738	1.339524	0.364	-1.41657	3.850046

Table 3.38 Test 2: The response of 3-month mortgage repo rates to discount rate changes ("Great Recession")

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.1636372	.0487712	0.001	-.2595115	-.067763
cfr	-.0263583	.0977414	0.788	-.2184979	.1657813
cdisr	.0330872	.3624525	0.927	-.6794203	.7455947
_cons	1.087429	1.336371	0.416	-1.539603	3.71446

Table 3.39 Test 3: The response of 3-month mortgage repo rates to discount rate changes ("Great Recession")

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.1765637	.0493379	0.000	-.2735526	-.0795748
mrpl2	-.0792302	.0493283	0.109	-.1762002	.0177398
cfr	-.0246813	.0975583	0.800	-.2164624	.1670997
cdisr	.0409496	.3617859	0.910	-.6702527	.7521519
_cons	1.181205	1.335068	0.377	-1.443286	3.805695

Table 3.40 Test 4: The response of 3-month mortgage repo rates to discount rate changes ("Great Recession")

mrp	Coef.	Std. Err.	P>|t|	[95% Conf. Interval]	
mrpl1	-.1632786	.0486978	0.001	-.2590078	-.0675494
cdisr	.0348303	.3619838	0.923	-.6767507	.7464112
_cons	1.081497	1.334674	0.418	-1.542181	3.705175

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