

# Arbitrage, liquidity and exit: The repo and federal funds markets before, during, and after the financial crisis

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## Abstract

This paper examines the linkages between the federal funds and repo markets, before, during, and after the financial crisis that began in August 2007. In particular, the paper investigates four issues: transmission of monetary policy, pricing of risk, the liquidity effects, and the effects of liquidity draining. The paper presents estimation results for a set of VEC and VAR models with GARCH error processes fitted for the effective federal funds rate and the overnight Treasury General Collateral repo rate. First, the results suggest that a pass through from the federal funds rate to the repo deteriorated somewhat during the zero lower bound period, likely due to limits to arbitrage and idiosyncratic market factors. Second, during the crisis, the pricing of federal funds, that is, of unsecured loans, indicated a marked jump in perceived credit risk. Third, the liquidity effect for the federal funds rate, that is, the change in the federal funds rate associated with an exogenous change in reserve balances, weakened greatly with the increase in supply of these balances over the crisis, implying a non-linear demand for federal funds. The liquidity effect for the repo rate, that is, the change in the repo rate associated with an exogenous change in supply of Treasury collateral, changed little, on net, over the crisis. Fourth, the paper shows simulations of the dynamic effects and balance sheet mechanics of liquidity draining on the federal funds and repo rates. The paper covers robustness checks such as fitting the models for other unsecured and secured overnight interest rates.

## 1 Introduction

How does monetary policy implementation work? The first step is for the Federal Open Market Committee (FOMC) to set a price for reserves. This price is called the target federal funds rate, or the desired level for the interest rate at which depository institutions (“banks”) lend balances at the Federal Reserve to other banks overnight.<sup>1</sup> For many years, open market operations—purchases and sales of U.S. Treasury and federal agency securities using repurchase agreements (repos)—were the Federal Reserve’s most often used tool for changing the level of reserves and thus implementing monetary policy.

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<sup>1</sup>Throughout this paper, we use “banks” in many places where we intend the slightly broader depository institution definition.

After the Federal Reserve initiates the monetary policy transmission process, the most immediate next step is for the federal funds rate to influence the behavior of other short-term interest rates. In order for monetary policy transmission to be effective, these other short-term interest rates should move with the federal funds rate. As the participants in the federal funds market and other short-term markets frequently overlap, in theory, all rate differences should be arbitrated away. As a result, it seems plausible that all short-term interest rates should move in tandem with the federal funds rate. In particular, one might think that the interest rate on repurchase agreements – the repo rate – and the federal funds rate have a special relationship, as both markets are involved in the earliest stages of the monetary policy transmission process. Indeed, it seems likely that these two rates would move together.

But do they? Although there are long periods when the repo rate and the federal funds rate move together, there are also notable times when they do not. For example, figure 1 displays the federal funds rate and the Treasury general collateral (GC) repo rate, or the rate charged on secured overnight lending against Treasury-issued collateral. Although for much of the sample, there appear to be only small differences between these two rates, there are spells when the spreads widen considerably and the rate movements seem decoupled. One might question whether the monetary policy transmission mechanism works during these periods, or whether the relationship between the rates fundamentally changes.

In order to provide perspective on these issues, this paper characterizes the relationship between the Treasury GC repo rate and the federal funds rate during three periods: a period of relative calm in financial markets, from 2002 to 2007, the early stages of the financial crisis, from August 2007 to December 2008, and post-December 2008, after the Federal Open Market Committee (FOMC) set a target range for the federal funds rate of 0 to 25 basis points.<sup>2</sup> We are able to use our analysis to investigate three key issues in the federal funds market and the repo market. The first is the description of the monetary policy transmission process. We characterize this by the length of time it takes for disequilibriums between the two rates to dissipate, or, in other words, how quickly movements in one rate affect movements in the other. We find that there is substantial variation in the speed of transmission over time.

The second issue we address is the pricing of risk in unsecured funding markets. Using a simple arbitrage model that includes a probability of default, we illustrate how the implied riskiness of counterparties as well as the premium placed on safe collateral increased as the financial crisis intensified.

Finally, the third issue we explore is the “liquidity effect,” or the short-run price response to a change in the level of balances. This issue has been explored extensively since the work of Hamilton (1997).<sup>3</sup> Importantly, we extend previous results by estimating a dynamic liquidity effect; that

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<sup>2</sup>On December 16, 2008, the FOMC decided to establish a target range for the federal funds rate of 0 to 0.25 percent. At that time, the FOMC anticipated that weak economic conditions would necessitate a low level of the funds rate for some time. In addition to the FOMC decision, the Board set the rate paid on required and excess reserves to 0.25 percent. As of this writing, about two years later, the target range for the federal funds rate and the rate paid on reserves remain at 0.25 percent.

<sup>3</sup>Extensions include Carpenter and Demiralp (2006), and Judson and Klee (2010).

is, we evaluate the effect of an increase in liquidity on both the federal funds and the repo rate, allowing a more complete picture of how changes in the supply of available funds affect the rates paid for these funds.

Using these three key results, we conduct forecasting exercises to illustrate the possible effect of reserve draining operations by the Federal Reserve on the federal funds rate and the repo rate. After the failure of Lehman Brothers, the Federal Reserve markedly expanded its balance sheet. As a result, the level of reserve balances ballooned, and currently is at about \$1 trillion. If the Federal Reserve engages in either asset sales or large-scale reverse repurchase agreements, not only would reserve balances increase, but it is likely that the federal funds rate and the repo rate would rise as a result. Overall, our estimates imply that for a little less than \$1 trillion in draining operations to achieve balances in line with required balances, and holding both the interest on excess reserves rate and the target rate constant, the federal funds rate would increase about 85 basis points from its current level.

One of the major contributions of this paper is a careful analysis of the interplay between two key rates for monetary policy implementation. To the best of our knowledge, there are few works using relatively modern econometric techniques that evaluate this relationship fully.<sup>4</sup> Given the increased focus on these markets and on their functioning during the financial crisis, it is important to uncover the factors that make them work together. In particular, there is a long literature evaluating the monetary policy transmission mechanism. But much of this previous work examines lower-frequency changes in interest rates, and then traces these changes through to real output and the rest of the economy. Often ignored – or assumed to work seamlessly – is the first step in this transmission, which is the link across short-term funding markets, where the federal funds rate should be somewhat of an anchor. Because the federal funds market and the repo market have the same participants, are both liquid, and have the same term, the rates should move together. Furthermore, monetary policy implementation – past, present, and future – often relied on both of these markets simultaneously, making it important from a policy perspective to understand fully the interaction between these markets. As we demonstrate in this paper, after the crisis, the two markets seem not to move together in the same way as before the crisis, making it important to understand how things changed and how the implementation of policy may function in the future.

The paper proceeds as follows. Section 2 provides background on key overnight funding markets, both secured and unsecured. Section 3 describes the empirical framework for the results reported in section 4. With these results in hand, section 5 provides calculations of the speed of adjustment across markets, the probability of default, and the dynamic liquidity effect. With these three pieces of information in hand, section 6 presents the possible effect of reserve draining measures on these rates and the following section puts the simulations into balance sheet pressures perspective. Section 8 concludes.

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<sup>4</sup>Recent work by Bartolini, Hilton, Sundaresan, and Tonetti (2010) investigates the relative valuation of different types of collateral that are used in open market operations.

## 2 Background

This section reviews basic facts on the repo market and the federal funds market, the two markets that are the focus of this paper, as well as discusses monetary policy implementation.

### 2.1 The markets

Both the repo market and the federal funds market are money markets. However, they differ in important ways, as will be described below.

#### The repo market

The market for repurchase agreements is one of the largest money markets in the world. Despite the fact that repo market volumes are much greater than those of the stock market, outside of the circle of money market aficionados, few had heard of it before the start of the financial crisis. To start, the definition of a repurchase agreement is a sale of a security coupled with an agreement to repurchase the security at a specified price at a later date.<sup>5</sup> It is economically similar to a collateralized loan, where the lender of cash receives securities as collateral, and the borrower pays the lender interest on the overnight loan the following day. From the perspective of the borrower of cash, the transaction is called a “repo,” and from the perspective of the lender of cash, it is a “reverse repo.”<sup>6</sup> If the rate on a repurchase agreement is low relative to other market rates, it indicates that the underlying collateral is in demand and relatively dear, and as a result, the borrower does not have to pay much interest for using the funds overnight. By contrast, if the rate on a repurchase agreement is relatively high, it signals a relative abundance of collateral, and the borrower has to pay a higher interest rate in order to obtain funds.

There are two main methods of clearing and settling repos: direct (delivery versus payment) and tri-party.<sup>7</sup> In a direct repo transaction, the holder of the securities initiates the transaction and the cash payment moves automatically as a result of the securities movement. Many of these transactions use the Fedwire Securities Settlement system for clearing and settlement, or they use the infrastructure provided by the Fixed Income Clearing Corporation (FICC). In a tri-party repo transaction, both the borrower and the lender of securities must hold accounts at a clearing bank (either JPMorgan Chase or Bank of New York). Clearing and settlement work much the same way as in a direct repo transaction, with a few exceptions. First, there is some netting of transactions in tri-party repo that does not necessarily exist in the direct repo world. Second, should the borrower of cash incur a daylight overdraft when the collateral is returned, the clearing bank generally extends a daylight overdraft to the borrower; within the delivery-versus-payment

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<sup>5</sup>“Frequently Asked Questions,” Federal Reserve Bank of New York, 2010.

<sup>6</sup>There is a quirk in nomenclature when discussing the repo market and the Federal Reserve’s balance sheet. For the Fed, repos are defined by the the effect on the *counterparty*. Therefore, if the Federal Reserve lends securities and borrows funds, it is called a reverse repo, and if the Federal Reserve lends cash and borrows securities, it is called a repo.

<sup>7</sup>Much of the information in this paragraph follows Federal Reserve Bank of New York (2010).

world, this function would be provided by the Federal Reserve if Fedwire were used. And third, tri-party repo platforms generally offer services to customers that minimize transactions costs, including efficient collateral allocation. For these reasons, tri-party repo has gained in popularity in recent years.

Data on aggregate repo market activity is not generally available.<sup>8</sup> However, there are a few sources of information on repo market volume that can help to characterize its size. One source is statistics compiled by the Federal Reserve Bank of New York (FRBNY) on repurchase agreements conducted by the primary dealers, which are the banks and broker-dealers that trade directly with the Open Market Desk (the “Desk”) at FRBNY for the purposes of open market operations. As shown in figure 3, within the primary dealer community, total repurchase agreement market volume in Treasury securities averaged about \$52 billion in 1994, and then started to climb steadily through the 2000s, peaking at a little below \$200 billion. Interestingly, the volume of repos brokers executed outside of the primary dealer community more than quadrupled in 10 years, while the volume within the community only doubled. At the onset of the crisis, repo market volume climbed even higher, but then backed down to pre-crisis levels near the end of 2009 and the start of 2010.

The broker-dealer volume reported above includes both direct trades and triparty trades. The main difference between the two types of trades is whether there is a bank acting as the custodial agent in the transaction. The tri-party market grew substantially over the past decade, and according to data gathered by FRBNY in April 2010, there was about \$474 billion in U.S. Treasury tri-party repo volume.<sup>9</sup> Overall, then, the data from the primary dealers likely represents a significant fraction of total repo market activity, but not necessarily all.

## **The federal funds market**

Federal funds are unsecured loans of reserve balances at Federal Reserve banks that depository institutions make to one another. The rate at which these transactions occur is called the federal funds rate and the market in which these transactions occur is the federal funds market. In many ways, the federal funds market is similar to the repo market, in that they are both used as short-term funding markets, have overlapping participants, and are generally very liquid. But, there are important differences. Fundamentally, the federal funds market is used by banks to buy funds in order to satisfy reserve requirements, or to sell funds in excess of those requirements. Banks satisfy reserve requirements on the basis of average balances held over a 14 day period, and previous research shows that funds rate behavior differed according to the day of the maintenance period.<sup>10</sup> Moreover, this research also provided evidence of a short-term “liquidity effect,” or a price response to changes in the level of reserve balances. be used directly to satisfy these requirements. In addition, partly because of federal funds’ unique ability to be used to satisfy reserve requirements, the federal funds market is more restricted than the repo market in its participants, which are

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<sup>8</sup>Some market observers attempt to estimate the size of the repo market; refer to Gorton (2010), for example.

<sup>9</sup>Federal Reserve Bank of New York, 2010.

<sup>10</sup>For example, refer to Hamilton (1996), Carpenter and Demiralp (2006), and Judson and Klee (2010).

limited to banks, government-sponsored enterprises (GSEs) and selected other entities. Edge Act and agreement corporations. This has the important implication that while all financial institutions are theoretically able to participate in the repo market, the federal funds market is limited only to selected institution types.

Even though the federal funds market has traditionally been very important for monetary policy implementation, the market is quite small and by many measures, federal funds market volume is much lower than repo market volume. For example, figure 4 plots federal funds transactions identified in the Fedwire data.<sup>11</sup> According to this series, federal funds market volume ranges from around \$100 billion in daily volume in 1998 to a peak above \$400 billion in 2008, before falling closer to \$300 billion in 2010. The data from the repo market suggest much higher volumes.

### Comparing the two

These observations regarding the size of the federal funds market relative to the size of the repo market are consistent with data from the Call reports, which suggest that commercial bank federal funds market volume is only a small share of total repo market volume, and that commercial banks' federal funds market activity is smaller than the repo market activity. As shown in figure 5, federal funds sold peaked at around \$250 billion near the start of the financial crisis, and then dropped to less than half that volume by March 2010. As a percentage of assets, federal funds peaked much earlier, in 2003. Notably, federal funds purchased generally exceeds federal funds sold, indicating that commercial banks are net buyers of funds.<sup>12</sup> Moreover, while federal funds sold stayed relatively steady from 2002 to 2007, securities purchased to resell, or reverse repos, rose at a moderate pace, and then began to rise rapidly through the end of 2008. Repos, or securities sold to be repurchased, peaked noticeably earlier than reverse repos, and at a higher level. Still, for a majority of the sample period, commercial banks had more of their balance sheets in repos than in federal funds, and consequently, were a more prominent share of the portfolio.

Information on combined federal funds and repo activity for commercial banks is also available. As shown in figure 6, compared to the quantity outstanding for the dealers, commercial bank participation in overnight funding markets constitutes only a small share. For both federal funds and repo combined, the amount outstanding for repos with banks and nonbanks reaches a maximum of only about \$750 billion, near the height of the crisis. Moreover, as a share of total assets, federal funds and repo combined are only about 10 percent of assets. One exception is the spike that occurs

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<sup>11</sup>The data on federal funds volume are constructed using proprietary transaction-level data from the Fedwire Funds Service, using an algorithm pioneered by Furfine (1999) to match and form plausible overnight funding transactions, likely related to the federal funds market. The algorithm matches an outgoing Fedwire funds transfer sent from one account and received by another with a corresponding incoming transfer on the next business day sent by the previous day's receiver and received by the previous day's sender. This pair of transfers is considered a federal funds transaction if the amount of the incoming transfer is equal to the amount of the outgoing transfer plus interest at a rate consistent with the rates reported by major federal funds brokers. However, because we have no independent way to verify if these are actual federal funds transactions, our identified trades and characteristics of these trades are subject to error.

<sup>12</sup>Commercial banks can purchase funds from other institutions in the federal funds market, including thrift institutions, foreign institutions, and GSEs.

on September 12, 2001, immediately following the terrorist attacks on the World Trade Center and which impacted communications and payment and settlement systems in lower Manhattan.

Even though the volumes in these markets are quite different and there is imperfect overlap between the two markets, over much of the past decade or so, these rates have moved together quite closely. Figure 2 plots the spread between the federal funds rate and the repo rate from 2002 to 2010. As is evident from the figure, these rates were similar up until 2007. Because federal funds transactions are unsecured while repo transactions are secured, the repo rate is usually a bit below federal funds. Spreads started to widen in the beginning of the financial crisis, from August 2007 onward, and then skyrocketed during the crisis as investors flocked to the relative safety of secured overnight lending in repo.

## 2.2 Monetary policy implementation

There is a special connection between the federal funds market and the repo market for Federal Reserve monetary policy implementation. In the textbook version of monetary policy implementation, the Federal Reserve buys securities from dealers in the repo market, which gives the dealers cash which they deposit in their bank's accounts, and the banks then proceed to sell the funds in the federal funds market. By sizing this "open market operation" appropriately, the Federal Reserve could ensure that the federal funds rate – the policy rate – was close to the target set by the Federal Open Market Committee (FOMC).

This operating procedure and target interest rate worked for many years. Repo rates and federal funds rates traded in line with each other, and longer-term interest rates moved up and down with the federal funds rate. According to Simmons (1954), repurchase agreements were used as part of the Federal Reserve System's operations since 1917. In addition, as documented by Friedman and Schwartz (1963), as early as the 1920s, open market operations were the Fed's preferred operating procedure, and the federal funds rate moved in line with the target rate. In addition, during the period before which the FOMC announced an explicit target federal funds rate, market participants would determine the new target federal funds rate by observing the sizes of the open market operations that would follow on the heels of an FOMC meeting. Although market participants arguably stopped looking for a signal regarding the stance of policy in repos after this date, open market operations remained an important tool of the Desk used almost daily to adjust the level of reserves precisely to ensure that the federal funds rate would trade close to the target federal funds rate.

Monetary policy implementation changed with the advent of the recent financial crisis, although not all at once. At the very start of the crisis in August 2007, the Federal Reserve relied on larger-than-normal repo operations to inject liquidity into the federal funds market. In addition, the Federal Reserve also used reverse repos as a tool to stabilize the total amount of reserve balances outstanding and add collateral back to the market in the wake of the Lehman Brothers failure. In the fall of 2008, the Federal Reserve conducted reverse repos in order to drain reserves from the system as well as to add some collateral back to the market. However, because reserve balances

were at elevated levels, the effective federal funds rate traded well below the target rate. In addition to the reverse repos, the Federal Reserve also conducted 28-day single-tranche repos in agency MBS collateral. These were established in order to provide dealers financing for agency MBS during a period when the spread between one month agency MBS repo and one-month Treasury GC repo was particularly wide.<sup>13</sup> Although there was a cessation in regular repo activity by the Desk in the early part of 2009, in 2010, the Desk conducted a series of small-value reverse repurchase agreements with a broad set of counterparties as part of its operational readiness program for tools to use in the future to drain reserve balances.

In sum, although the use of the repo market to facilitate monetary policy implementation has certainly changed in recent years, overall, it is still expected to be a possible tool for monetary policy implementation going forward.

### 3 Empirical preliminaries and framework

This section first performs some preliminary data analysis to provide justification for the statistical strategy used in this paper. Second, it describes the primary estimating question of interest and reviews its ability to capture the three aspects of the market on which this paper focuses.

#### 3.1 Preliminary statistical analysis

The primary data used in this study are daily observations on the effective federal funds rate and the overnight Treasury GC repo rate from January 2, 2002 to June 16, 2010.<sup>14</sup> The daily effective federal funds rate is a volume-weighted average of rates on trades arranged by major brokers calculated and published by the Federal Reserve Bank of New York. The Treasury GC repo rate is a collateral-weighted average of a survey of all primary dealers conducted daily between 8:00 a.m. and 9:00 a.m.<sup>15</sup> Because a large fraction of federal funds market activity takes place in the late afternoon, the federal funds rate implicitly measures late-day funding activity, while the repo rate we use necessarily focuses on trading earlier in the day. Nevertheless, both measure activity when the respective markets are most active.<sup>16</sup>

The spread and correlations between federal funds and repo reviewed in section 2 suggest that there could be a cointegrating relationship between these two series. To test for this possibility, table 1 presents augmented Dickey-Fuller tests to determine whether these series have unit roots.<sup>17</sup> We perform the tests over three subsamples: from January 2, 2002 to August 8, 2007; from August

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<sup>13</sup>For details, refer to Federal Reserve Bank of New York (2009).

<sup>14</sup>In work not shown, we tested to see whether the introduction of a new discount window regime in 2003 affected our results; it did not.

<sup>15</sup>Bartolini et al. (2010) also use this series in their work on the repo market.

<sup>16</sup>The Desk obtains a federal funds indicative rate at 9:00 a.m. each morning. Although volumes associated with this rate are generally limited, we performed our analysis using this rate to see if using the end-of-day rate is different from this morning rate. Overall, we found the results to be both qualitatively and quantitatively similar.

<sup>17</sup>We include a constant in the specification for all tests. In addition, the optimal lag length used is based on the Schwarz information criterion (SIC).



9, 2007 to December 15, 2008; and from September 1, 2008 to June 2010. While the null of a unit root is accepted for the first two periods, the null of a unit root is rejected for the year-and-a-half sample for the last period with very high balances.<sup>18</sup>

Given that these series have unit roots over some sample periods, we next use the Johansen test to determine whether the series are cointegrated. As shown in table 2, the series are cointegrated in both the relatively stable period before the August 2007 start of the crisis, and in the window between the start of the crisis and the failure of Lehman Brothers. However, after the failure of Lehman Brothers and the concomitant rise in reserve balances, the cointegrating relationship breaks down.

Taken together, these results suggests the existence of distinct regimes for the relationship between the federal funds rate and the repo rate. As a result, portions of our analysis will divide the period up into these separate regimes and report statistics separately.

### 3.2 Empirical framework

The empirical framework we use elucidates three results we outlined earlier, namely that (1) the speed of monetary policy transmission slowed over the financial crisis; (2) implied probabilities of default climbed in the crisis; and (3) while the liquidity effect appears to exist throughout our entire sample, the dynamics of this effect have changed over time.

Our primary tool for evaluating these claims is a vector error-correction model to investigate the relationship between federal funds and Treasury GC repo. We posit that the federal funds rate and the repo rate have the following relationship:

$$\Delta \mathbf{x}_t = \alpha (\beta' \mathbf{x}_{t-1} + \mathbf{c}_0) + \Phi(L) \Delta \mathbf{x}_t + \Xi \mathbf{Z}_t + \mathbf{e}_t \quad (1)$$

where  $\mathbf{x}_t$  is the vector of federal funds and Treasury GC repo interest rates.  $\beta$  is the cointegrating vector for the error correction term that characterizes the long-run relationship between the repo and the federal funds rate. After testing for the proper specification using the Akaike Information Criterion (AIC), we include a constant  $c_0$  in the error correction term, that is,  $\mathbf{w}_{t-1} = \beta' \mathbf{x}_{t-1} + \mathbf{c}_0$ . The  $\alpha$  vector contains the adjustment factor coefficients. Because the  $\alpha$  and  $\beta$  coefficients are not identified, we use the normalization proposed by Johansen (1995) in what follows. This normalization sets the first  $m$  components of the  $\beta$  vector to 1, where  $m$  is the number of cointegrating relationships.

The  $\Phi(L)$  are autoregressive coefficients to be estimated. We use three lags of all interest rates in the specification as suggested by the Schwarz Information Criterion (SIC) test.<sup>19</sup> Furthermore,

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<sup>18</sup>In results not reported, we performed Bai-Perron tests to select breaks in the relationship between the two series. The dates chosen by these tests were similar to our dates based on discrete market events, and the qualitative results were largely unaffected by the method of choice of sample periods.

<sup>19</sup>Although some tests occasionally reveal statistically significant autocorrelated lags further out, these are generally ten business days or more in the past. We tried to balance a more parsimonious specification versus controlling for all of these lags, and moreover, we feel that movements more than two weeks previous are likely irrelevant once other controls are included in the specification.

significance of all coefficients is reported with respect to Bollerslev-Wooldridge robust standard errors.

In addition to the lagged values of the repo rate and the effective rate, the other variables included are factors that likely shift the relationship between the effective rate and the repo rate on a daily basis. These are captured in the  $\mathbf{Z}_t$  vector, with coefficients to be estimated,  $\xi$ . We specify  $\mathbf{Z}_t$  as

$$\mathbf{Z}_t = (\text{risk}_t, \text{repomarket}_t, \text{ffmarket}_t, \text{calendar}_t) \quad (2)$$

where the four terms represent groups of variables that proxy for financial market risk measures (a few are similar to those used in Collin-Dufrense et al (2002)), plus some factors that are specific controls for the funds market and for the repo market, and a vector of specific calendar effects.

To start reviewing each group individually, the first group of factors controls for overall indications of financial risk. Over the estimation period, market sentiment changed dramatically with the advent of the financial crisis. As a result, indicators such as the Libor-OIS spread, bank capital ratios, and the monetary policy outlook – as proxied by the slope of the yield curve (the 10-year Treasury rate less the 2-year Treasury rate) – generally reflected more negative sentiment about the financial markets and the economy towards the the second half of the sample.

The second group includes factors related to the repo market. Because repo rates experience pronounced movements on Treasury issuance days, and these effects generally linger for a few days after the issuance, we include net Treasury issuance, both contemporaneous and lagged by a day. Also included is a measure of how heavily weighted primary dealers’ books are towards trades with other dealers versus with non-dealers.<sup>20</sup> This gives some idea of market concentration in the Treasury market. To address market functioning, fails in Treasury securities are included as an independent variable; these are reported by primary dealers to FRBNY on a weekly basis. In addition, actions on the SOMA Treasury portfolio are added as controls, including the level of Treasury securities lent through the SOMA securities lending programs. Again, securities lending tends to increase during times of market stress and for particular CUSIPs that are considered to be trading on “special” in the market.<sup>21</sup>

The third group includes factors specific to the federal funds market. Included is the the “miss” for the day’s forecast of reserve balances captures how much over-or-under- supply of reserve balances—relative to the forecast—was present in the market on that day. We also use a number of controls for the size of and participation in the federal funds market, including federal funds market volume, the number of sellers, and specifically, the quantity sold by the government sponsored enterprises (GSEs). In addition, we control for days when there is movement in the target federal funds rate; this variable equals the change in the target rate on days of FOMC announcements, but equals zero on all other days.

The final group of factors is included in *calendar*, a vector of maintenance period and other

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<sup>20</sup>This variable is defined as transactions outside the dealer community as a share of total transactions. The data source is the FR2004.

<sup>21</sup>For a discussion of specials markets in Treasury securities, refer to Fisher (2002) and others.

calendar effects. Previous work, including Hamilton (1996) and others, has shown that these are significantly correlated with changes in the federal funds rate. Repo rates also move with calendar effects, as shown by Happ (1984) and Fleming, Hrungr and Keane (2010). Reasons for these patterns include elevated payment flows on beginning-, mid-, and end-month dates, as well as Treasury coupon securities issuance on these dates. Moreover, research including Griffiths and Winters (1997) show that repo rates tend to exhibit maintenance period patterns as well, suggesting that there is some co-movement in the fed funds and repo rates that derives from the maintenance period construct.

Preliminary estimation results suggest that there exists heteroskedasticity of the residuals for which controls are needed.<sup>22</sup> As a result, in conjunction with the mean equation described above, we also estimate a variance equation, of the form

$$\mathbf{H}_t = \mathbf{\Gamma}'\mathbf{\Gamma} + \mathbf{A} \cdot (\mathbf{e}_{t-1} * \mathbf{e}_{t-1} \cdot (\mathbf{e}_{t-1} < \mathbf{0})) * (\mathbf{e}_{t-1} * \mathbf{e}_{t-1} \cdot (\mathbf{e}_{t-1} < \mathbf{0}))' \mathbf{A} + \mathbf{B}\mathbf{e}_{t-1}\mathbf{e}_{t-1}'\mathbf{B} + \mathbf{D}'\mathbf{F}_{t-1}\mathbf{D} \quad (3)$$

where  $\mathbf{H}_t = [h_{1t}h_{2t}]'$  is a vector of the conditional variances;  $\mathbf{\Gamma}$ ,  $\mathbf{A}$ ,  $\mathbf{B}$  and  $\mathbf{D}$  are vectors to be estimated;  $\mathbf{e}_t$  is the vector of residuals; and  $\mathbf{F}_t$  is a vector of exogenous explanatory variables. This is the BEKK form of generalized autoregressive conditional heteroskedasticity, first described by Engle and Kroner (1995).<sup>23</sup>

Because we are interested in the linkages between these two rates over different time periods, we run the vector error correction model over multiple samples. While our baseline methodology is a vector error correction model with GARCH errors, in the last sample period, as discussed in section 3.1, the rates do not have unit roots and are therefore not cointegrated. As a result, we specify a vector autoregression and evaluate

$$\mathbf{x}_t = \mu_0 + \mathbf{\Phi}(\mathbf{L})\mathbf{x}_t + \mathbf{\Xi}\mathbf{Z}_t + \mathbf{e}_t \quad (4)$$

which generally uses the same control variables as the vector error correction model. Similar to the cointegrated case, we use a GARCH specification for the second moment equation and report results with Bollerslev-Wooldridge robust standard errors.

Operationally, we employ a two-stage estimation procedure similar to Engle and Granger (1987). In the first stage, we test for cointegration of the repo rate and the federal funds rate. After establishing this, we construct the cointegrating term using ordinary least squares. We then use this constructed term as an independent variable in our system GARCH estimation. Although it is possible that some efficiency is lost using this procedure, it allows us to use a GARCH specification relatively easily in the second stage estimation.

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<sup>22</sup>We perform a White heteroskedasticity test which handily rejects the hypothesis of homoskedasticity in all three samples.

<sup>23</sup>BEKK is an acronym for Baba, Engle, Kraft and Kroner.

## 4 Results

This section reviews the results over the three sample periods. Overall, the results suggest that the repo rate and the federal funds rate were cointegrated during normal times and during the first stages of the financial crisis. However, transmission of policy from the federal funds market to the repo market slowed, and this relationship broke down after the introduction of the 0-25 basis point target range for the federal funds rate in late December 2008. In addition, the spread between the two rates widened over time, consistent with a possible perceived higher probability of default in the federal funds market. Finally, the effect of changes in balances on the federal funds rate and in the amount of collateral on the repo rate shifted over time, suggesting some nonlinearities in the demand for these.

The following subsections explain these trends in more detail.

### 4.1 Normal times: 2002-2007

Table 4 provides key results for each sample. The results for the early part of the sample, a time of relative calm in financial markets, are presented in the left column. The top panel presents the ordinary least squares results used to construct the cointegrating term. As shown by the constant term within the cointegrating relationship, the stationary series that is formed by the difference between the federal funds rate and the repo rate has a mean of about 2 basis points. This can be interpreted as the steady-state risk premium of federal funds over repo. In addition, over the early sample, the cointegrating equation coefficients (the  $\beta$ s) suggest a relationship between federal funds and repo that is close to 1-to-1.

With the cointegrating term in hand, table 5 reports results from estimating the second stage vector error correction model with GARCH errors. The first set of columns report results for the repo equation; the second set report results for the federal funds equation. As indicated by the  $\alpha$ , or cointegrating term, coefficients, the movement from disequilibrium is roughly three times as fast for repo as for federal funds. We interpret statistically significant  $\alpha$  terms as consistent with the existence of arbitrage; that is, traders are willing to exploit pricing anomalies and trade until the differences between the two rates are minimized.

There are three possible reasons why pricing anomalies are more likely to remain unexploited in the funds market than in the repo market. First, over this sample period, the Desk was actively manipulating the federal funds market in order to achieve an effective rate near the target federal funds rate. As a result, the ability for the federal funds rate to adjust quickly to movements in the repo rate may have been muted.

Second, there may be some difference in adjustment speeds that can be attributed to differences in composition in the two markets, with smaller institutions less likely to exploit arbitrage opportunities than larger ones. As an example, as shown in figure 7, Call Report data indicate that both on the asset and liability sides of the balance sheet, repo holdings are concentrated in larger banks, while fed funds holdings tend to be more spread out. For example, the top 10 banks account for

over 80 percent of commercial bank holdings of repo assets in some years, while the share of fed funds liabilities remains below 50 percent for nearly all of the sample, and medium-sized banks comprise a much larger share. If one assumes that larger, more sophisticated institutions are more likely to arbitrage differences, and that nonbank participants in the repo market also tend to be larger, more sophisticated institutions, then repo should necessarily move back faster to equilibrium than federal funds.

And third, because repo transactions are secured, participants may be more willing to exploit pricing anomalies than they would if transactions were unsecured, as in the federal funds market. Despite the fact that adjustment is at a lower pace in the federal funds market than in the repo market, a likelihood ratio test indicates that the  $\alpha$  parameter is statistically different from zero, suggesting that the adjustment speed is still significant. This implies that federal funds adjusts when there are deviations of the repo rate and the federal funds rate from their long-run relationship, even though the Federal Reserve was actively manipulating the federal funds rate during most of this period.

The next three rows display the effects of past changes in rates on current ones. Own lags of the variables have mixed statistical significance out to the third lag. Past changes in the repo rate are negatively correlated with current changes, although significance is relatively limited. By contrast, changes in the federal funds rate are negatively correlated with the contemporaneous change in the federal funds rate, out to the third lag. This result suggests some mean reversion, in that a large negative change in the repo rate might be associated with a large positive change in the federal funds rate later in the week. Taken together, the results for cross-market effects suggest causality from the repo market to the federal funds market, but limited causality from the federal funds market to the repo market. As displayed in table 3, Granger causality tests indicate that the repo market is more likely to drive the federal funds market than vice versa. Although it appears from these short-run dynamics that the repo market is “ground zero” for monetary policy implementation, the fact that the two series are cointegrated in the long run suggest that these movements are transitory in nature and are not necessarily significant for long-run monetary policy transmission.

The estimated coefficients on the factors that control for overall indications of financial risk are broadly in line with intuition. During this period of relative calm, movements in the Libor-OIS spread were likely idiosyncratic, and therefore, did not have much connection to repo rates or to federal funds rates. Similarly, changes in the overall capital ratio of commercial banks were not associated with materially different changes in repo or federal funds rates. By contrast to these other indicators, the change in the slope of the yield curve is associated with a more negative change in federal funds rates; that is, as the difference between the ten-year rate and the two-year rate increases, changes in the federal funds rate become more negative. Interestingly, the repo rate is unaffected by changes in the slope of the yield curve.

Not surprisingly, there are different effects on the repo rate and on the funds rate of our various market-specific controls. Turning to those for the repo rate, the next few lines in the table indicate

that net Treasury issuance generally pushes up the repo rate. However, the effect of net Treasury issuance tends to dissipate after the first day, implying that markets quickly return to their long-run relationship during this period. Still, according to the estimated coefficients, for a \$10 billion increase in Treasury issuance, the change in the repo rate increases by about half a basis point. By contrast, net Treasury issuance has minimal impact on the federal funds market. As shown in the next line, the composition of dealers' books appears to have little impact on either the repo market or the federal funds market in this period. In addition, occasions with large amounts of fails in the Treasury market were also relatively sporadic over this period, and as such, changes in fails had little bearing on movements in the repo or federal funds rate.

For those variables included specifically to address conditions in the federal funds market, the coefficient on the "miss" term is not significantly different from zero in the repo equation, but is negative and significantly different from zero in the federal funds equation. The coefficient on the miss suggests that for a \$1 billion miss that adds balances, the effective federal funds rate declines by 1/2 a basis point. A positive change in federal funds market volume is associated with a movement up in the federal funds rate, but no statistically significant movement in the repo rate. By contrast, increases in GSE loan amounts tend to push both rates down – the point estimates suggest that this effect is a touch stronger for the repo rate than for the federal funds rate. This could be capturing a supply effect: if the GSEs have excess cash to invest, rates in both markets trade lower.

The final set of coefficients displays various day-of-week controls. Day-of-week factors are significantly different from the first day of the maintenance period for repo on five out of nine days, while for federal funds, six out of nine days have significantly different coefficients. Day-of-month factors are more often statistically significant for federal funds than for repo as well, although mid-month dates are significant for both rates. Month-ends generally see a jump up in rates in the federal funds market, likely because payment flows are relatively elevated. Both federal funds and repo tend to drop on the last day of the year – about 5 to 10 basis points for each. In addition, the coefficients on the exogenous terms in the variance equation suggest that month-ends have higher volatility than average, while mid-months have somewhat less volatility.

## **4.2 Crisis: August 2007 to December 2008**

On August 9, 2007, BNP Paribas stopped redemptions on three investment funds and the financial crisis began. Over the next year-and-a-half, the Federal Reserve took a variety of unconventional policy measures in order to combat the financial crisis. During this period, the Federal Reserve cut the target federal funds rate nearly 5 percentage points and flooded the federal funds market with reserve balances in order to provide ample liquidity.

Despite these changes, the federal funds rate and the repo rate appeared to have stayed together. Table 6 presents results for the crisis, from August 2007 through December 2008. As shown in the top panel, the mean of the stationary series that is formed by the difference between the federal funds rate and the repo rate jumped from about 2 basis points to 18 basis points, consistent with a

perceived higher counterparty default probability. Moreover, although the repo market continues to adjust to arbitrage opportunities between the funds market and the repo market, after the start of the financial crisis in August 2007, albeit at a lower pace, evidence of significant adjustment in the federal funds market is somewhat weaker. There are a few reasons why the speed of adjustment in both markets may have changed. First, credit concerns in the unsecured federal funds market may have been greater than those in the secured repo market, creating conditions where investors were willing to leave arbitrage opportunities unexploited.<sup>24</sup> Second, some federal funds market investors may have experienced capital limitations, and were unwilling to expand their balance sheets in order to take advantage of arbitrage opportunities, similar to the phenomenon described by Brunnermeier and Pedersen (2009). Finally, the federal funds market was likely changing to some degree at this point in time, both in terms of participants and in the composition of reserve balances (for example, the introduction of the term auction facility (TAF) might have altered participation somewhat).

A couple of simple examples clarify these explanations. In cases when the repo rate is high relative to the funds rate, a bank that wants to arbitrage would be likely to lend cash in the repo market and borrow it in the funds market. This would have the effect of pushing down the repo rate and pushing up the federal funds rate. However, due to the introduction of the TAF and other credit facilities by the Federal Reserve, banks engaging in this arbitrage may not have to clamor for funds in the market, and instead, use cash on hand. As a result, arbitrage and thus movement in the funds rate may be limited. In cases when the repo rate is low relative to the funds rate. In this case, a bank might borrow cash in the repo market, pushing up the repo rate, and then lend the cash in the funds market, pushing down the funds rate. This arbitrage could fail if the arbitrageur had concerns about the creditworthiness of counterparties, and the potential to earn profit would be swamped by the possibility of losses on the investment.

Interestingly, while the repo rate and the federal funds rate remain cointegrated after the start of the crisis, the repo rate no longer Granger-causes the federal funds rate, as it did in the earlier part of the sample, the federal funds rate Granger-causes the repo rate. One conjecture is that the Federal Reserve refrained from daily open market operations later in the sample, instead letting the federal funds rate float, with the repo rate following suit. In a regime where the funds rate is actively managed, the Desk may change its open market operation so that it adjusts to overall funding market conditions, which can be proxied by the early morning repo rate. Another way to explain the change in the Granger-causality results is that there may be other factors that are simultaneously affecting both markets, which cause the rates to continue to move together. Indeed, the  $\alpha$  coefficients are insignificant for federal funds during this time period, indicating a possible lack of arbitrage between the two markets. Although the repo rate is moving, the federal funds rate fails to respond directly, and instead, both rates move in tandem to outside factors. This is evident from the coefficients on some of the exogenous variables, particularly those that affect

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<sup>24</sup>This phenomenon occurred in other markets as well; refer to Coffey, Hrungrung and Sarkar (2009) for evidence for evidence from the foreign exchange market.

the repo market. For example, the coefficients on the month-end date becomes more negative and significant, while the coefficients on net Treasury issuance become more positive and significant. The repo rate is also more sensitive to changes in risk-weighted capital ratios; as these decline, repo rates move down as well. By contrast, month-end dates do not see significantly different rate behavior in the funds market, and changes in risk-weighted capital have a relatively more muted effect on the funds rate. Positive changes in the Libor-OIS spread push down repo rates, while positive changes in the slope of the yield curve are associated with decreases in the federal funds rate.

The next few lines show the correlations of the market-specific factors with the repo and federal funds rates. Increases in net Treasury issuance are associated with higher repo rates; the effect lingers for an extra day as the market absorbs the higher quantity of collateral. The effect of net Treasury issuance on the funds market is limited during this period, however. Composition effects of dealers' books appear to have a strong influence on the repo rate during this period. As the share of transactions with entities other than dealers grew, the sensitivity of movements also became more pronounced. For a 1 percentage point change in this ratio, the repo rate increases by about 4 basis points. If cash is abundant relative to collateral, the repo rate moves up. In addition, the level of the "factors miss," or the forecast miss for the supply of reserve balances at the Federal Reserve, is not correlated with changes in either the repo rate or the funds rate over the period. This result is likely highly influenced by the inclusion of the very high balances period from October to December 2008 in the sample; in results not reported, the factors miss is significant and negatively correlated with changes in the federal funds rate.

[CHECK THIS PARAGRAPH.] Finally, maintenance-period frequency calendar effects are less relevant in the crisis period, particularly those at the end of the maintenance period. By contrast, the month-end, quarter-end, and year-end effects are magnified, with changes in funds and repo rates exceeding 130 and 165 basis points, respectively.

### **4.3 "Extended period": December 2008 to June 2010**

On December 16, 2008, amid weak economic conditions, elevated reserve balances and a very low effective rate, the FOMC lowered its target rate to a range of 0 to 25 basis points. To date, the target rate has remained at that level, and reserve balances are still quite elevated. Moreover, even though the interest rate paid on reserve balances stayed at 25 basis points, the federal funds rate has consistently traded below that level. Perhaps in part due to these factors, table 1 shows that during this period, the repo rate and the funds rate fail to exhibit unit roots, and as a result, the two rates are no longer cointegrated. As a result, we use the specification in equation 4.

Table 7 displays the results. Turning first to the lagged effects of the two rates, the results suggest that both own lags and cross-lags affect the repo rate, but only own lags of the federal funds rate significantly influence movements in that rate. This offers further evidence of some, but not complete, decoupling of the two rates. The fact that the coefficients are positive is consistent with some persistence in changes in rates that was less evident in earlier periods; that is, rates were



more likely to revert back to long-run averages during calmer markets.

Although movements in the Libor-OIS spread had little effect on the repo market, they did have a limited effect on the federal funds market. Conversely, increases in capital ratios were associated with increases in the repo rate, but not correlated with the federal funds rate. Taken together, these two results could indicate that as banks became more well-capitalized and some riskiness of institutions abated, there was less relative demand for secured funding. Changes in the slope of the yield curve had no effect on changes in either the repo rate or the federal funds rate during this period as well. Because policy was likely seen as being on hold for “an extended period,” it is possible that other factors that might cause movements in this spread would not be associated with rate movements in very short-term funding markets.

By contrast to a period with low reserve balances, net Treasury issuance influences changes in both the repo rate and the federal funds rate. Part of the explanation for the influence on the federal funds rate was a fundamental change in the cash management practices of the Treasury that occurred in the fall of 2008. Before this time, as shown in the top panel of figure 8, the Treasury targeted an account balance at the Federal Reserve at a relatively constant level, typically \$5 billion. Excess cash was invested in depository institution accounts through the Treasury Tax and Loan (TT&L) account system; the rate of return was typically the effective federal funds rate less 25 basis points. Because of this relationship, all other things equal, a higher balance in the TGA implied less reserve balances, and vice versa. A relatively constant TGA balance contributed to the smooth implementation of monetary policy, as the Desk did not need to anticipate movements in the TGA over a longer period so that it could perform offsetting repos in order to maintain reserve balances at a desired level. However, that might necessitate a repo operation to offset. After the effective rate plummeted and reserve balances rose, the return that the Treasury received on TT&L investments was negligible, and the Desk ceased to conduct open market operations on a daily basis to target a specific level of reserve balances. As a result of these policy changes, as shown in the bottom panel of figure 8, the TGA level became highly correlated with net Treasury issuance, as positive net issuance creates a cash inflow for the Treasury, while negative net issuance represents a cash outflow.

The cash management practices of the GSEs morphed after they were placed into conservatorship in September 2008. This change is reflected in the coefficient on the change in GSE lending term, which has a positive coefficient for the repo equation and an insignificant one in the federal funds equation. With excess cash on hand, it seems reasonable that GSEs invest cash in the market for which they receive the highest return; not surprisingly, the repo rate moves up as GSE investments move up.

As a final exercise, we examine the effects of the flow of large-scale asset purchases (LSAPs) on changes in the repo rate and the federal funds rate. While the flow has no effect on the repo rate, there is limited effect on the funds rate, suggesting that the increase in balances due to LSAPs pushes the funds rate down; the size of this effect is fairly small, and the significance is marginal, at a 6 percent confidence level.

## 5 Implications of empirical results

The next few subsections use the parameters estimated above to perform a series of policy experiments. The first set examines the monetary policy transmission mechanism, the second explores the probability of default in the federal funds market, and the third performs simulations of the possible effects on the funds rate and the repo rate of engaging in large-scale reverse repurchase agreements to drain reserves balances.

### 5.1 Monetary policy transmission

Our first exercise evaluates the effectiveness of the monetary policy transmission mechanism over the different sample periods. To start, the  $\alpha$  terms estimated above give some clue as to the ability of changes in the funds rate to transmit to other financial markets. As reviewed above, in general, if markets were in disequilibrium, movements were faster in the repo market than in the funds market, although the speeds-of-adjustment changed across sample periods.

These results are clearly reflected in figure 9. The top panel plots the implied speed of adjustment for the repo rate in days for a one percentage point change in the long-run relationship between the repo rate and the federal funds rate. In the pre-crisis period, the average length of time it took for the repo rate to adjust back to its longer-run average relationship with the federal funds market was between one and two days. Apparently, the crisis slowed down the speeds of adjustment, as shown by the early crisis line; adjustment speeds were about 80 percent of what they were before the crisis hit.

In general, the federal funds market consistently exhibits slower adjustment than the repo market. In the pre-crisis period, the federal funds rate adjusted at less than a third of the pace of the repo market. After the crisis began in August 2007, adjustment was very much close to zero, as the parameter estimate implies that a 1 unit shock to the funds rate would take more than 10 days to revert back to the longer-run equilibrium. , and for some periods, failed to adjust at all.

What do these relative rates mean? We take the faster speed of adjustment in the repo market relative to the funds market as indicating that the repo rate adjusted to the funds rate. The funds rate was continuously managed by the Desk in order to stay close to the target federal funds rate. As a result, the repo rate was quicker-to-adjust to disequilibria. In this sense, the funds rate was able to transmit the intended rate to the repo market, offering evidence that the daily transmission of monetary policy was functioning. Moreover, it also suggests that the arbitrage of differences between the two rates was faster in the repo market than in the funds market, perhaps due to the former's collateralized nature and larger participants. In the later crisis periods, the funds rate stopped adjusting to disequilibria altogether, although the repo rate continued to adjust. To some extent, this shows that there was still some arbitrage in the repo market, but much less in the funds market. Credit concerns may have driven some parties out of the federal funds market, leaving arbitrage opportunities unexploited.

## 5.2 Probabilty of default

In order to fix ideas, we present a simple framework for the relationship between secured and unsecured lending. Following Barro (1976), we assume that a loan of amount  $L$  is made from lender to a borrower today and the full principal and interest comes due tomorrow. We assume that there are two types of loan contracts in the economy—an unsecured contract and a secured contract—each for an overnight loan of \$1. Borrowers renege on both the principal and interest payment with probability  $p_f$  and  $p_r$  under the unsecured and secured contracts respectively, possibly reflecting differences in borrower characteristics. For simplicity, we assume that in case of a default of the unsecured borrower the lender gets nothing. Although, the secured loans are backed by collateral, secured lending is actually not risk free: in case of a default the collateral might not be recovered fully or it might be not sufficient ex post to cover the principal, for example, due to a drop in the market value of that collateral. The parameter  $0 \leq \delta \leq 1$  captures the recovery rate of the loan principal. (For simplicity, we ignore overcollateralization, that is, high margins to protect the lender against drops in the ex post value of collateral.)

Lenders are assumed to be risk neutral and, hence, arbitrage should, all else equal, ensure that the lender's expected return from secured lending be the same as that from unsecured lending. Suppose the unsecured loan contract specifies an interest rate of  $f$ , whereas the secured loan contract specifies an interest rate of  $r$ . The expected returns of a lender in the unsecured and secured markets— $E(R_f)$  and  $E(R_r)$  respectively—are given by

$$E(R_f) = (1 - p_f)f + p_f 0, \quad (5)$$

and

$$E(R_r) = (1 - p_r)r + p_r\delta. \quad (6)$$

Assuming no impediments to arbitrage, in equilibrium, the two returns should be equal,  $E(R_f) = E(R_r)$ . Rearranging the equilibrium condition gives

$$r = \frac{1 - p_f}{1 - p_r}f - \frac{p_r}{1 - p_r}\delta = \beta f - c_0 \quad (7)$$

where  $\beta = \frac{1 - p_f}{1 - p_r}$  and  $c_0 = \frac{p_r}{1 - p_r}\delta$ . Note that the relationship  $r = \beta f - c_0$  resembles a cointegrating vector. Hence, an estimated cointegrating vector should give us an idea about the ratio of no-default probabilities and a product of the repo default probability and recovery rate. The estimation results suggest the default probabilities are fairly close since the  $\beta$  is about 1.<sup>25</sup> Hence, the equation simplifies to

$$f - r = \frac{p}{1 - p}\delta, \quad (8)$$

implying that the spread between the unsecured and secured rates increases with either an increase

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<sup>25</sup>We cannot formally test the hypothesis whether  $\beta = 1$  in our econometric framework; however, the results of a VEC estimated using Johansen's maximum likelihood procedure suggest that we cannot reject the hypothesis that  $\beta = 1$ .

in the recovery rate,  $\delta$ , or an increase in the default probability,  $p$ .

Obviously, the same value of the spread between the federal funds and repo rates is consistent with a continuum of combinations of recovery rates default probabilities. To trace all these combinations, we construct a default probability–recover rate isocurve, a  $P - \delta$  isocurve for short, for each value of the estimated  $c_0$ . The isocurve for period  $j$  is given by

$$p = \frac{c_{0j}}{1 + c_{0j} - \delta}, \tag{9}$$

where  $c_{0j}$  is the estimated  $c_0$  for period  $j$ .

The isocurves corresponding to the  $c_0$  of about 0.02 estimated for the January 2002 - August 2007 period and the  $c_0$  of about 0.18 estimated for the August 2007 - December 2008 are shown in figure 10. The January 2002 - August 2007 isocurve is much lower than the August 2007 - December 2008 curve: At any recovery rate the implied probability of default is much higher in the later period than that in the earlier period. While the early period might be characterized as the period with high recovery rates (that is, stable collateral market values), the later period might be characterized as the period with low recovery rates. Nevertheless, the implied probabilities of default in that period are much higher than that for the earlier period. For example, at the recovery rate of 80 percent the implied probability of default for the later period is about 50 percent, while that for the earlier period is about 10 percent. We conclude that despite a possible decline in the recovery rate, the probability of default jumped notably in the later period.

### 5.3 Dynamic liquidity effects

Another key contribution of this paper is an estimate of a dynamic “liquidity effect.” The liquidity effect is a negative relationship between a money measure and an interest rate. In particular, there is a demand curve for some type of money that depends negatively on an interest rate. The liquidity effect is related to the slope of this demand curve. Methodologies and evidence are mixed. In lower frequency data, there is often a lack of correlation between monetary aggregates and interest rates. By contrast, in high frequency data, Hamilton (1997) and others find a significant liquidity effect at a daily frequency.

In a traditional liquidity effect estimation framework, the demand for reserve balances is usually posited as a (possibly nonlinear) function:

$$D_t = f(f_t, S_t, Z_t) + e_t \tag{10}$$

where  $f_t$  is fed funds rate,  $S_t$  is an exogenous shifter of reserves supply and  $Z_t$  is a set of controls.  $e_t$  is an error term, likely specified as a GARCH process. There are a few possible shortcomings of this framework. An important omission, in light of the evidence presented in earlier sections, is that there are limited dynamic demand adjustments. More specifically, there are no cross effects between the fed funds and repo markets.

We can use the vector error correction model specification presented above in equation 1 to

evaluate a dynamic liquidity effect. For example, we can rewrite the model as

$$\begin{aligned}
u_t &= r_t - \beta f_t + c_0 \\
\Delta r_t &= \Phi_{rr}(L)\Delta r_t + \underbrace{\Phi_{rf}(L)\Delta f_t}_{\text{cross effect}} + \alpha_r u_{t-1} + \gamma_r m_t + \underbrace{\Phi_r(L)T_t}_{\text{liq. effect}} + e_{r,t} \\
\Delta f_t &= \underbrace{\Phi_{fr}(L)\Delta r_t}_{\text{cross effect}} + \Phi_{ff}(L)\Delta f_t + \alpha_f u_{t-1} + \underbrace{\gamma_f m_t}_{\text{liq. effect}} + \Phi_f(L)T_t + e_{f,t} \\
(e_{r,t}, e_{f,t}) &\sim GARCH(1,1)
\end{aligned}$$

where  $u_t$  is the cointegrating error,  $r_t$  is the repo rate,  $f_t$  is the fed funds rate,  $m_t$  is the reserves supply miss,  $T_t$  is net Treasury issuance. In addition, we can rewrite the vector autoregression model as

$$\begin{aligned}
r_t &= \Phi_{rr}(L)r_t + \underbrace{\Phi_{rf}(L)f_t}_{\text{cross effect}} + \underbrace{\gamma_r TGA_t + \Phi_r(L)T_t}_{\text{liq. effect}} + e_{r,t} \\
f_t &= \underbrace{\Phi_{fr}(L)r_t}_{\text{cross effect}} + \Phi_{ff}(L)f_t + \underbrace{\gamma_f TGA_t + \Phi_f(L)T_t}_{\text{liq. effect}} + e_{f,t} \\
(e_{r,t}, e_{f,t}) &\sim GARCH(1,1)
\end{aligned}$$

where  $TGA_t$  is the Treasury General Account at the Federal Reserve Bank of New York.

Given this structure, we can reframe the results in table 4 as the following for the normal period:

$$\begin{aligned}
u_t &= r_t - 0.99f_t + 1.91 \\
\Delta r_t &= -0.21u_{t-1} + \underbrace{0.05T_t}_{\text{liq. effect}} + e_{r,t} \\
\Delta f_t &= \underbrace{-0.14\Delta r_{t-1}}_{\text{cross effect}} - 0.21\Delta f_{t-1} - 0.15\Delta f_{t-2} - 0.09\Delta f_{t-3} + 0.07u_{t-1} - \underbrace{0.52m_t}_{\text{liq. effect}} + e_{f,t}
\end{aligned}$$

as the following for the crisis period:

$$\begin{aligned}
u_t &= r_t - 0.96f_t + 18.33 \\
\Delta r_t &= -0.12\Delta r_{t-2} - 0.05\Delta r_{t-3} + \underbrace{0.21\Delta f_{t-2} + 0.08\Delta f_{t-3}}_{\text{cross effect}} - 0.17u_{t-1} + 0.15m_t + \underbrace{0.25T_t + 0.09T_{t-1}}_{\text{liq. effect}} + e_{r,t} \\
\Delta f_t &= \underbrace{-0.04\Delta r_{t-3}}_{\text{cross effect}} - 0.16\Delta f_{t-2} + 0.02u_{t-1} + e_{f,t}
\end{aligned}$$

and as the following for the “extended period”:

$$\begin{aligned}
 r_t &= 0.63r_{t-1} + 0.02r_{t-2} + 0.15r_{t-3} + \underbrace{0.47f_{t-1} + 0.04f_{t-2} - 0.35f_{t-3}}_{\text{cross effect}} + \underbrace{-0.01TGA_t + 0.05T_t + 0.02T_{t-1}}_{\text{liq. effect}} + e_{r,t} \\
 f_t &= \underbrace{0.12r_{t-1} + 0.13r_{t-3}}_{\text{cross effect}} + 1.05f_{t-1} - 0.41f_{t-2} + \underbrace{0.01TGA_t - 0.01T_{t-1}}_{\text{liq. effect}} + e_{f,t}
 \end{aligned}$$

These parameter estimates are used in the exercises below that forecast the effect of large-scale reverse repurchase agreements used to drain reserve balances on the effective rate. A key implication of the results above should be highlighted, however. The results suggest that the effect of Treasury issuance on repo rates is roughly unchanged, on net, over the entire sample. In the normal period, repo rates moved down 5bp per \$100B in net issuance. During the crisis, this sensitivity jumped to 25bp per \$100B in net issuance. However, the results suggest that in the extended period, this sensitivity dropped back again to 5bp per \$100B in net issuance. The common magnitude of this result could imply that the parameter estimates for one period may be able to be applied in a different one, despite the possibility of fundamental changes in these markets.

## 6 Forecasting the effect of reverse repurchase agreements on the effective rate

We can use the estimates of the liquidity effect to forecast the effect of reverse repurchase agreements on the effective rate. One of the measures currently undergoing operational tests for draining reserves are reverse repurchase agreements with a wide set of counterparties; that is, a counterparty list that includes primary dealers as well as other entities.<sup>26</sup> The results presented above allow us to evaluate how this program might affect money market interest rates. It is important to recognize that large scale reverse repos could potentially have direct and indirect effects on both the Treasury GC repo rate and the federal funds rate. Direct effects on Treasury GC repo would be through collateral available to market participants. By contrast, direct effects on the federal funds rate would likely be through the draining of reserve balances. However, consistent with the results presented above, there would likely be cross, or indirect, effects between the repo rate and the funds rate that could amplify some effects, outside of the direct effects of draining collateral or reserve balances. In the exercises that follow, we set all factors other than those depicted here to their sample-average levels in order to condition on relatively normal circumstances in the markets.

Overall, the results suggest that large-scale draining of reserve balances might exert weak upward pressure on the federal funds and repo rates at high levels of balances, but should exert strong upward pressure at lower levels. To illustrate this phenomenon, figure 6 shows the hypothetical effects of draining nearly \$1 trillion in total balances. Because demand for balances is likely non-linear, we apply the parameter estimates from the December 2008 to June 2010 to evaluate the

<sup>26</sup>For more information on eligible counterparties, refer to [http://www.newyorkfed.org/markets/rrp\\_counterparties.html](http://www.newyorkfed.org/markets/rrp_counterparties.html).

effects of draining the first \$900 billion in balances, and we use the parameter estimates from the January 2002 to August 2007 to evaluate draining balances down to about \$20 billion, close to the average level of required operating balances, or the amount of balances that banks are required to hold in order to satisfy reserve requirements as well as clearing needs.

As shown in the top two panels of figure 11, we assume two different patterns for draining reserve balances. The first, depicted by the blue line in the top left panel, is a fast approach, where \$900 billion in balances is drained over the course of 10 days. The second, shown by the red line, is a more gradual approach, where \$900 billion is drained over 30 days. The former strategy requires individual repo operations to be larger, while the latter relaxes this requirement. In both scenarios, however, as shown in the top right panel, the cumulative effect on reserve balances is the same.

The middle two panels show the effect of the draining on rates. As shown in the left panel, repo rates initially climb about 30 basis points, before falling and reaching an equilibrium interest rate that is about 5 basis points above the baseline. By contrast, the federal funds rate initially climbs up to 55 basis points, before settling at a rate about 35 basis points above the baseline. The peak rates are higher under scenario 1 than under scenario 2, but the equilibrium rates are the same.

The bottom panel depicts the behavior of the spread between the federal funds rate. Because the federal funds rate is driven up to a much higher level than the repo rate, the spread widens to a fairly substantial 25 basis points.

The dynamics for draining the final \$80 billion in reserve balances are slightly different. As shown in figure 12, even though the total amount of collateral removed from the market is less, the middle left panel shows that the effect on the repo rate is more substantial and persistent: repo rates rise about 40 basis points and stay elevated. By contrast, the effect on the federal funds rate is somewhat more limited, with rates increasing only about 15 basis points overall. The net effect of these dynamics is to cause a narrowing of the spread, as shown in the bottom panel.

One caveat of these results is that they depend on the assumption that the relevant parameters of the demand function will not change substantially from those that are estimated on past data. Given the introduction of interest on reserves in the fall of 2008, there is some chance that demand for reserve balances fundamentally changed since the early part of our sample – for example, since 2002. Still, we see scope for the relevance of this exercise, as it at least attempts to characterize the dynamics that still exist, as well as the possibility of differences in demand for balances as the level of balances approaches that of required operating balances.

## **7 Balance sheet mechanics of reverse repurchase agreements**

A large-scale reverse repo affects balance sheets of several types of entities: the Federal Reserve, depository institutions, dealers and mutual funds. The following stylized exercise, shown in figures 13 and 14, illustrates the main effects. Note that dealers' and mutual funds' balance sheets

have been combined into one: since dealers are typically cash borrowers and funds are cash lenders, for simplicity, it makes sense, to present a "netted" balance for the these two entity types. Note also that the figures show both the first and second round effects of a reverse repo. The first round effects cover immediate changes in the balances sheets of the involved entity types. The second round effects show possible balance sheet adjustments in the aftermath of the operation. In this exercise, the Federal Reserve conducts a \$500 billion reverse repo, the immediate effect of which is to drain \$500 billion in reserve balances, to reduce dealer/mutual funds deposits at depository institutions by \$500 billion, and to bias the composition of assets of dealers/mutual funds towards repos, see figure 13. Clearly, the balance sheet of depository institutions shrinks with the outflow of deposits due to dealers/mutual funds and reduction in reserve balances holdings. In contrast, the size of the balance sheet of the Federal Reserve and dealers/mutual funds remains constant. Because of the reverse repo, dealers/mutual funds are short on cash and long on collateral. This bias towards repos pushes up the repo rate in the short run (and our reverse repo simulations capture that). The higher repo rate boosts the federal funds rate, which has been already propelled by the reduction in supply of reserve balances. Over the time, see figure 14,dealers/mutual funds adjust their balances sheet by selling their outright holdings or doing repos to increase their holdings of cash. The shift of their balance sheet composition towards cash puts some downward pressure on the repo rate (and our reverse repo simulations capture that in the long run). Because of leverage constraints, dealers cannot adjust their balance sheet fully, so the repo rate in the long run remains above the repo rate before the large-scale reverse repo (again as the simulations show). The reduction in the size of the balance sheet of depository institutions, assuming no change in their capital, implies a lower leverage ratio (a higher capital ratio) than these institutions had initially. The "excess" capital gives these institutions an opportunity to raise more deposits and possibly increase lending or bank credit more broadly. The last step might seem tenuous though, as the depository institutions might prefer to the capital ratios to stay high in anticipation of strict regulatory capital regulation such as Basell III.

## 8 Conclusion

Financial markets experienced remarkable changes over the financial crisis, and money markets were no exception. This paper attempts to characterize the changes in these markets and to use these characterizations to address situations that could occur should operations one day return to "normal." Along the way, we showed how the speed of monetary policy transmission changed during the crisis; how banks were compensated for the possibility of default in the federal funds market; and how the demand curve for reserve balances morphed over time.

In sum, our results suggest that monetary policy transmission still functioned through a good part of the crisis. The link changed somewhat as reserve balances ballooned and the zero lower bound for short-term interest rates came about. Still our results suggest that draining balances should help restore relationship. And, although we don not address it specifically, our results are



likely robust to the explicit modeling of interest on excess reserves.

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**Figure 1: Federal funds and Treasury GC repo**

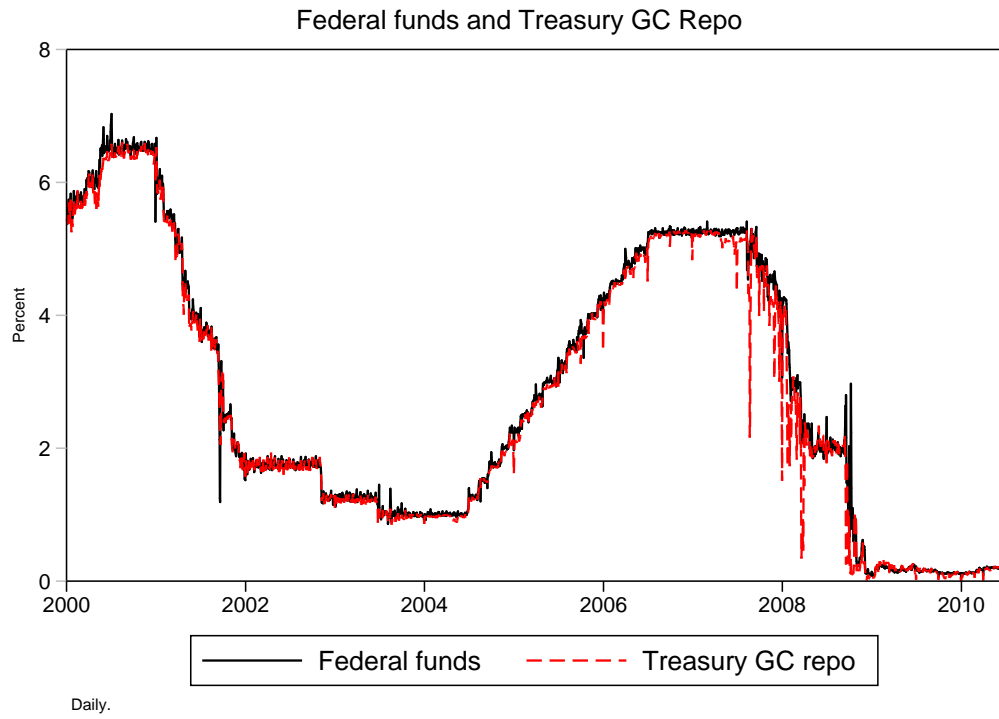
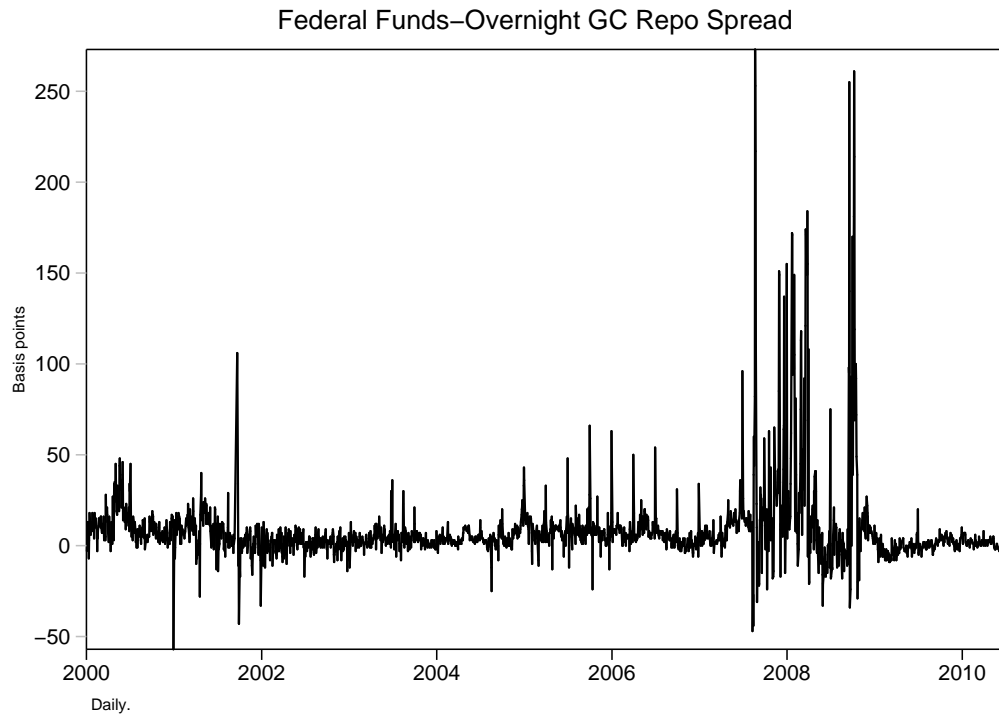
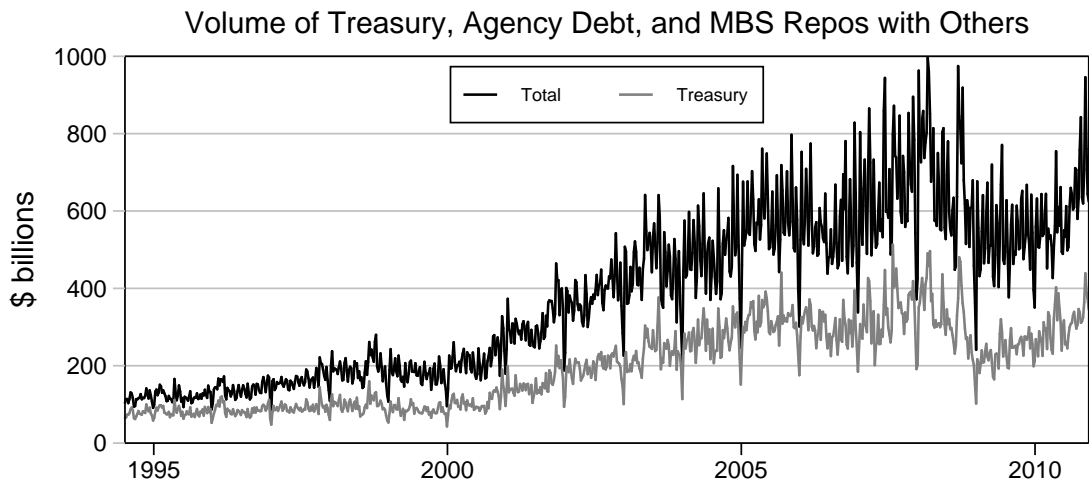
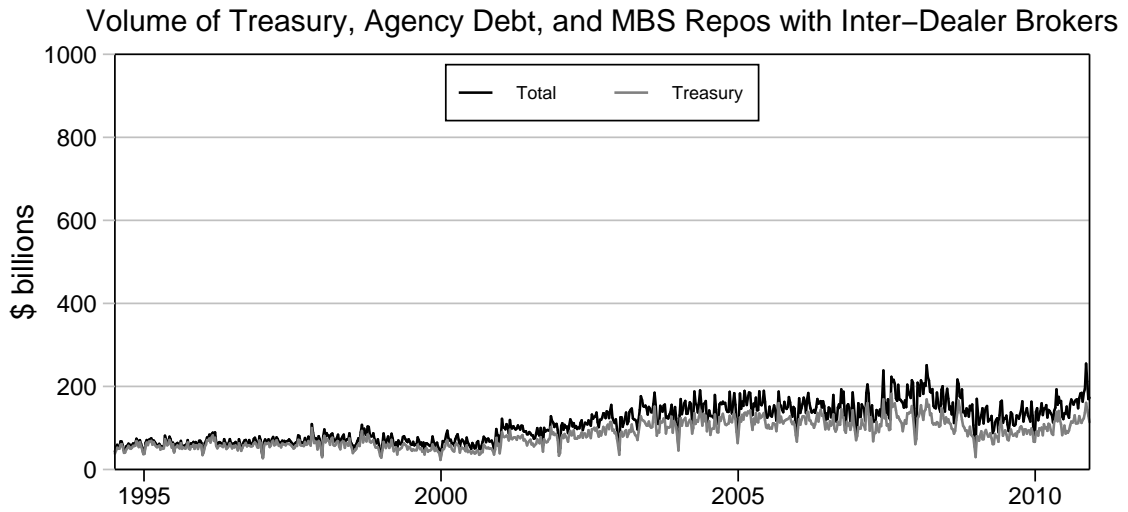


Figure 2: Spread between federal funds and Treasury GC repo

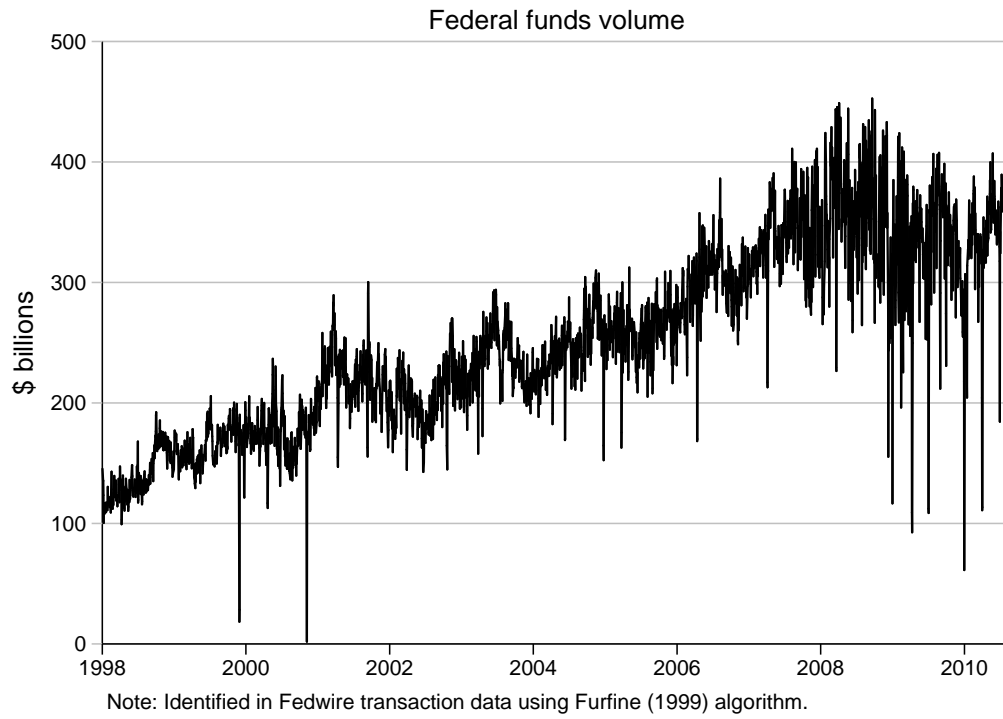


**Figure 3: Primary dealers repurchase agreement volume**



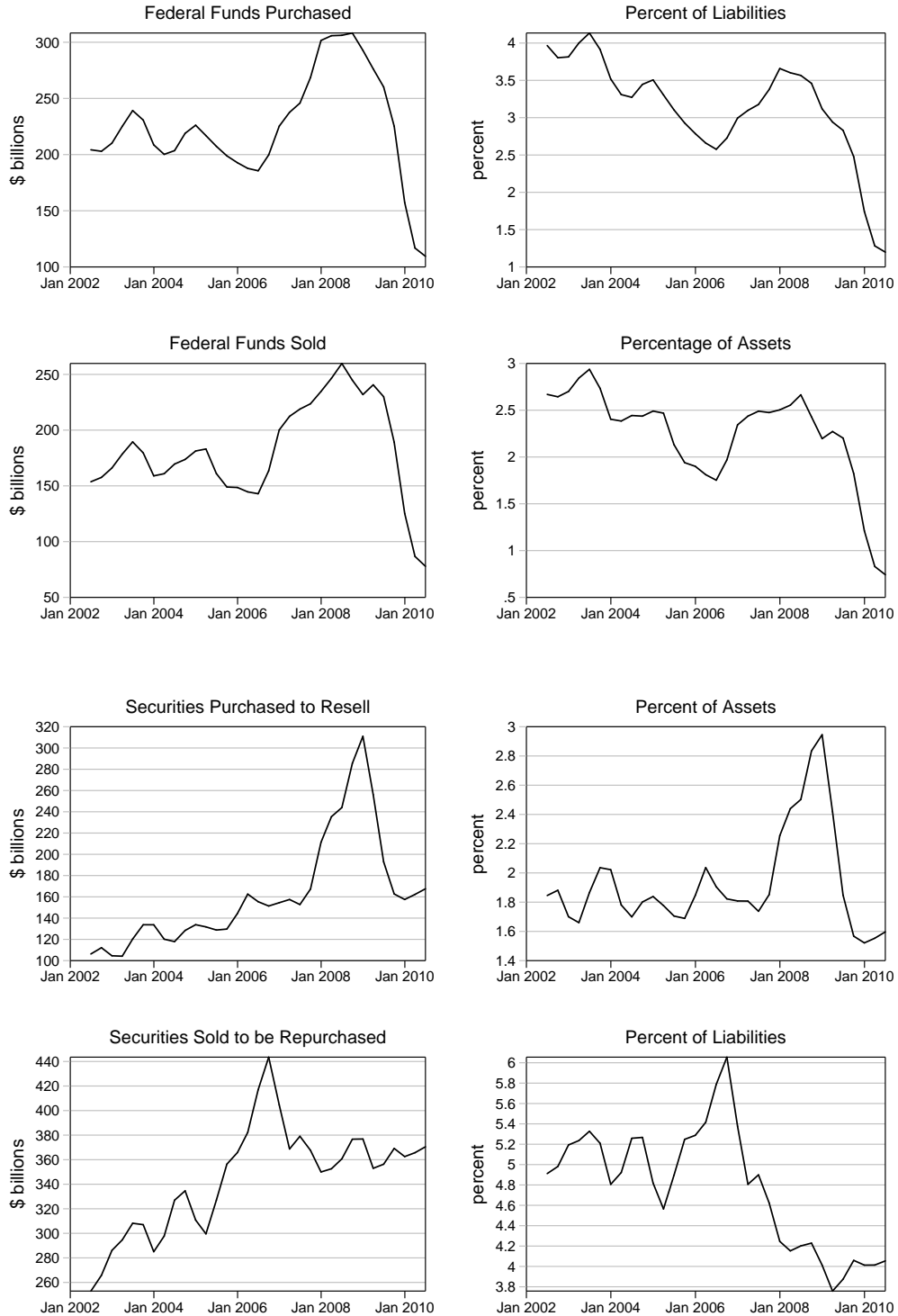
Source: FR2004.

Figure 4: Federal funds market volume

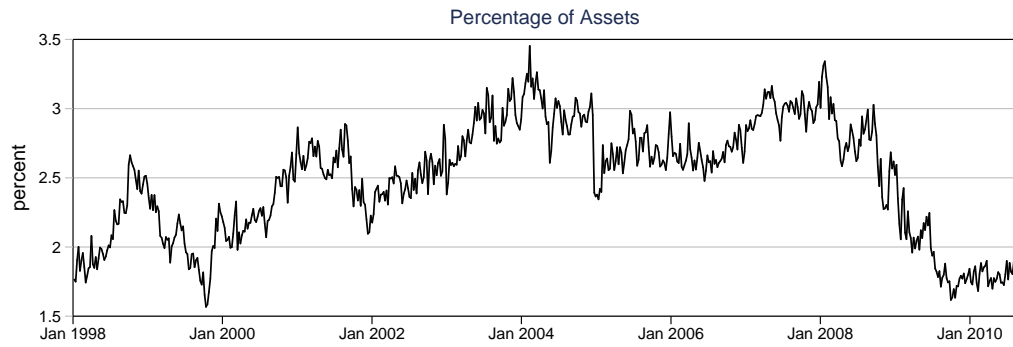
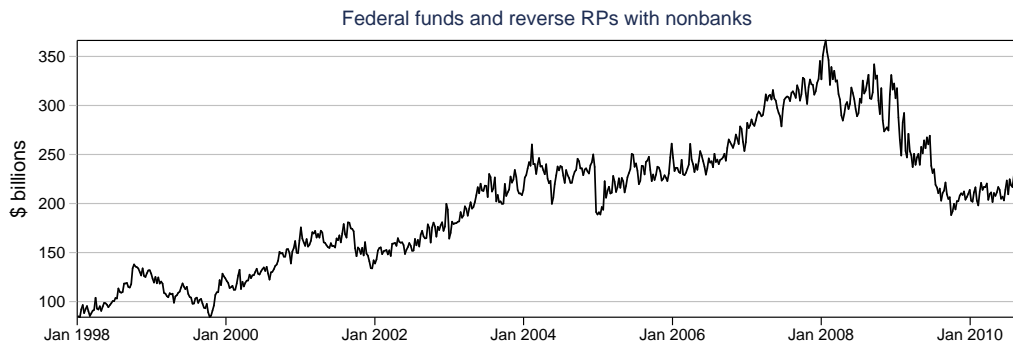
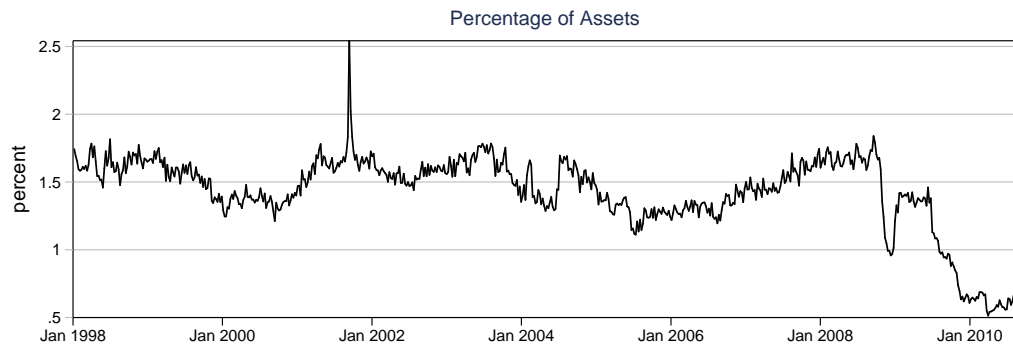
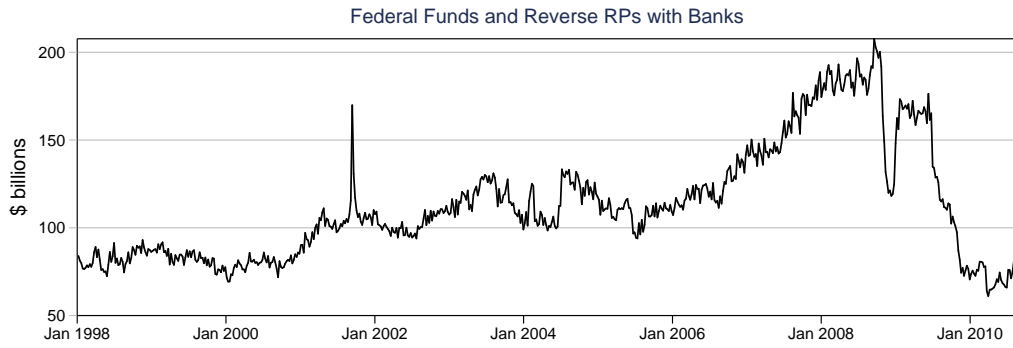




**Figure 5: Federal funds and repos at commercial banks: Quarterly**



**Figure 6: Federal funds and repos at commercial banks: Weekly**



**Figure 7: Share of repo and federal funds, by bank asset size**

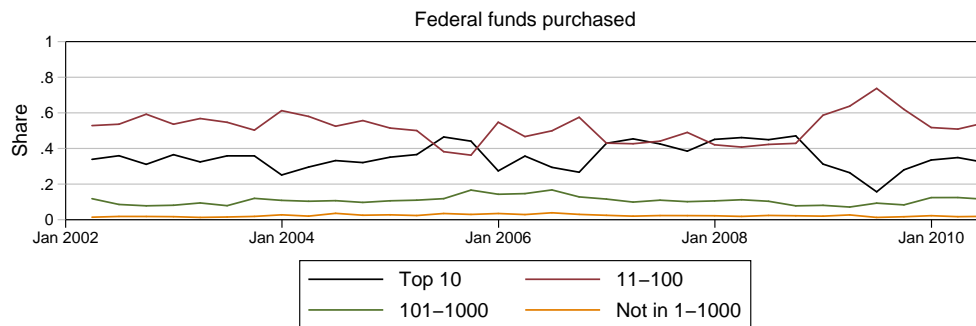
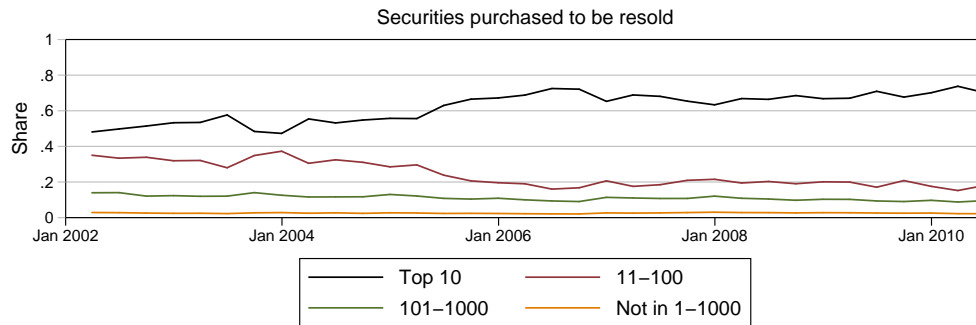
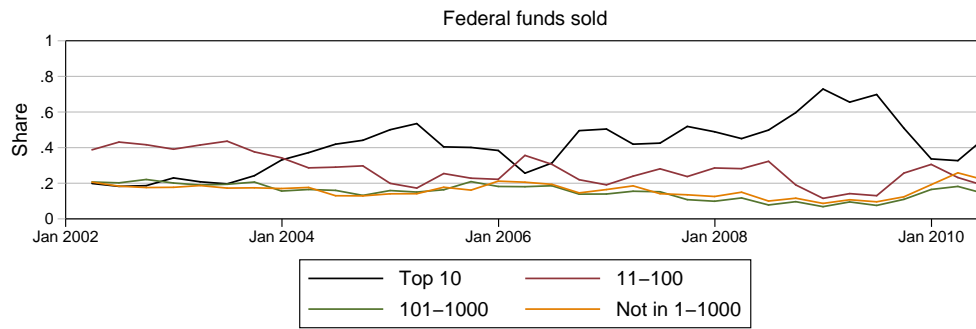
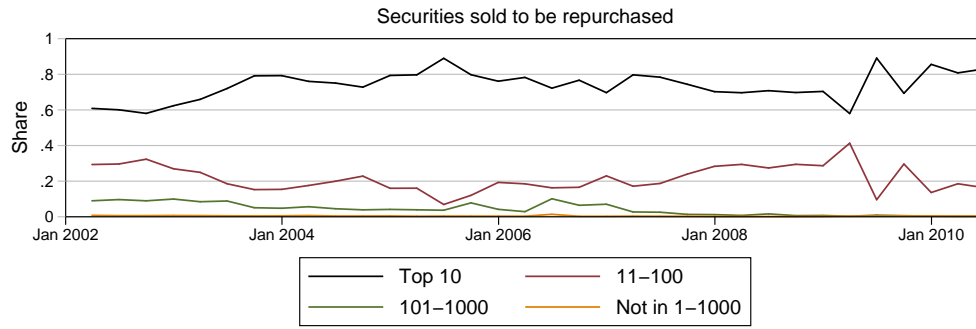
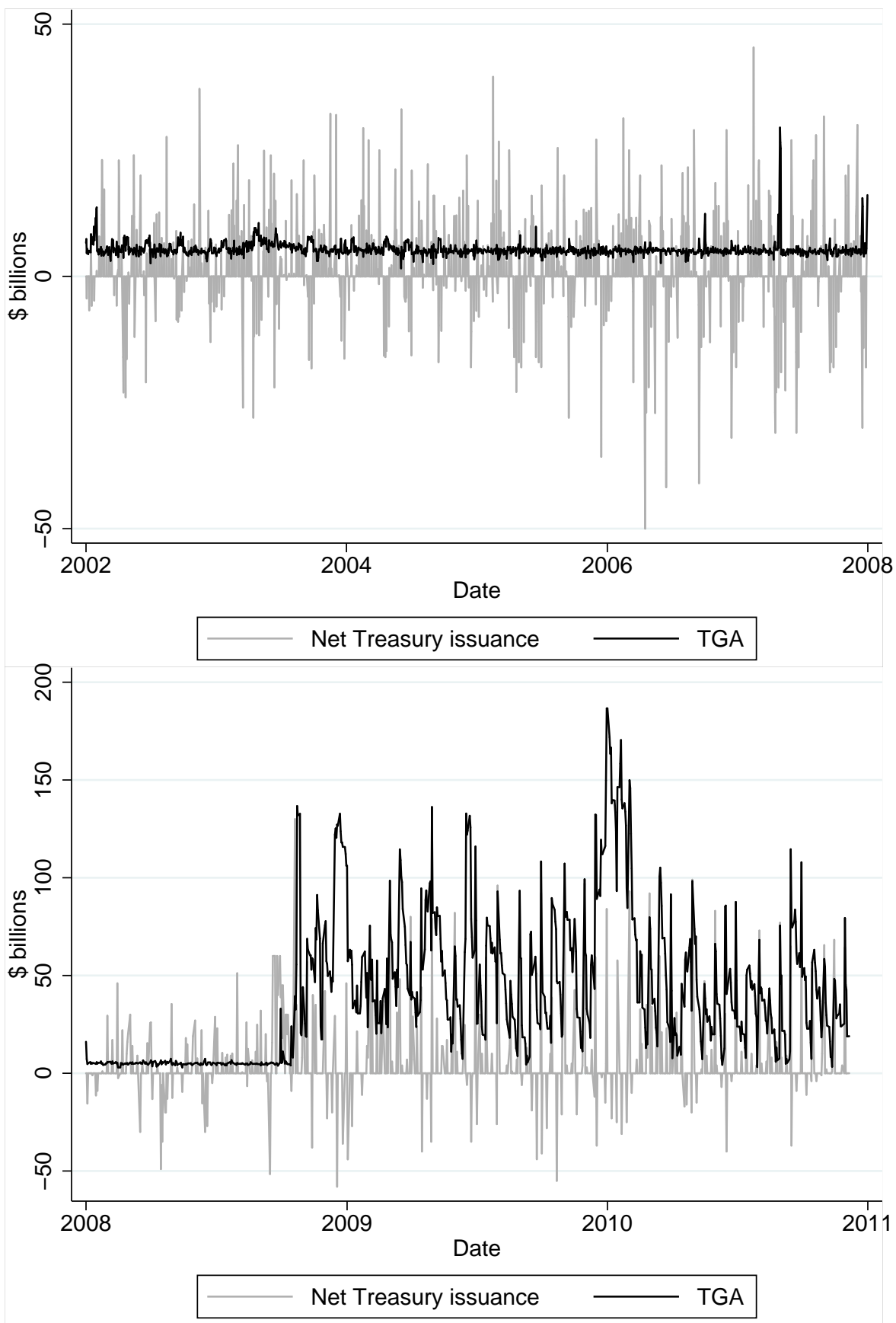


Figure 8: Net Treasury issuance and Treasury General Account (TGA) balance



### Figure 9: Speeds of adjustment

Overnight Treasury GC Repo Rate

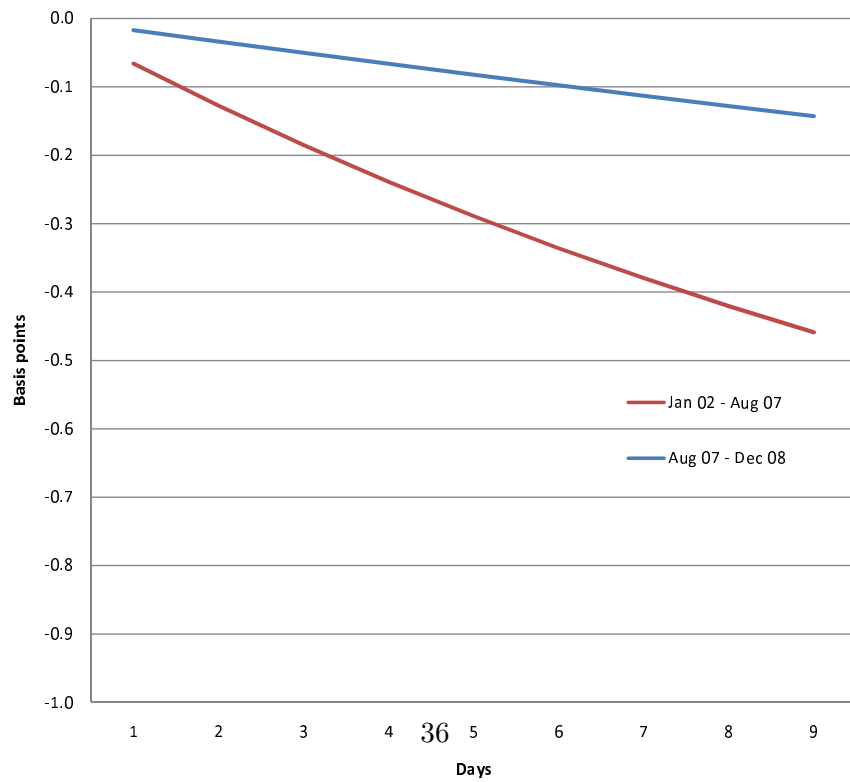
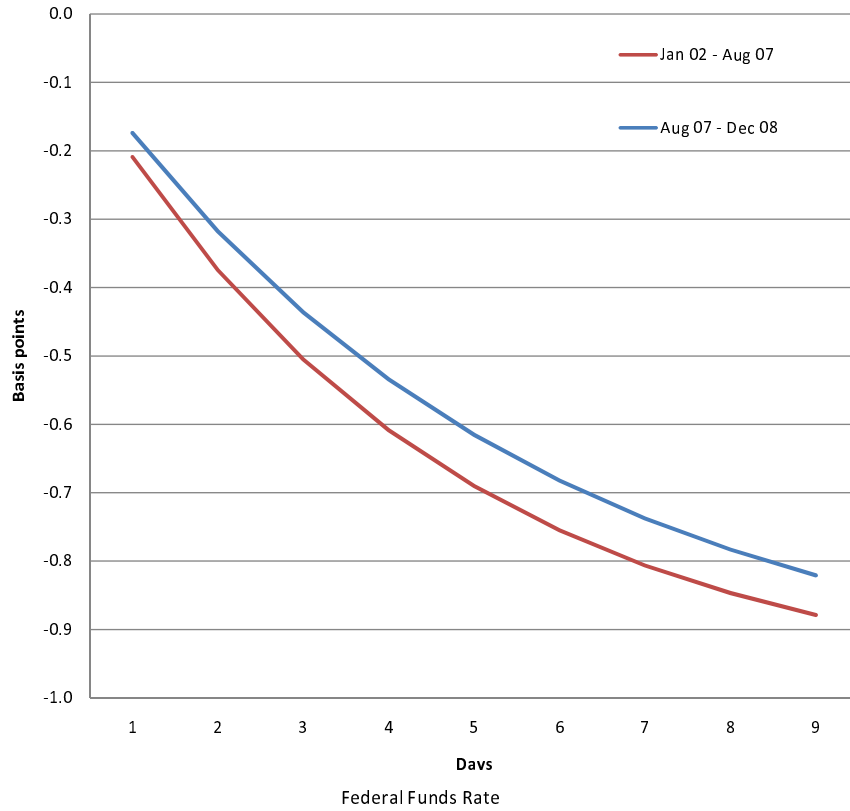


Figure 10: P- $\delta$  isocurves

P-delta isocurves

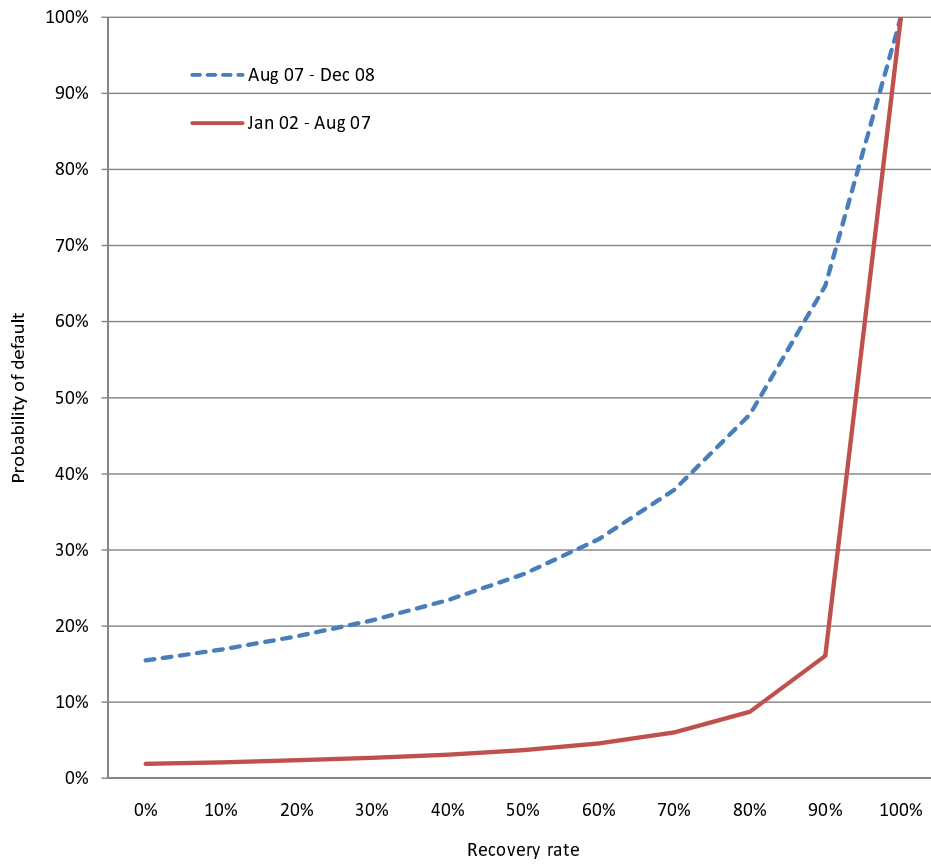


Figure 11: Draining the first \$900 billion

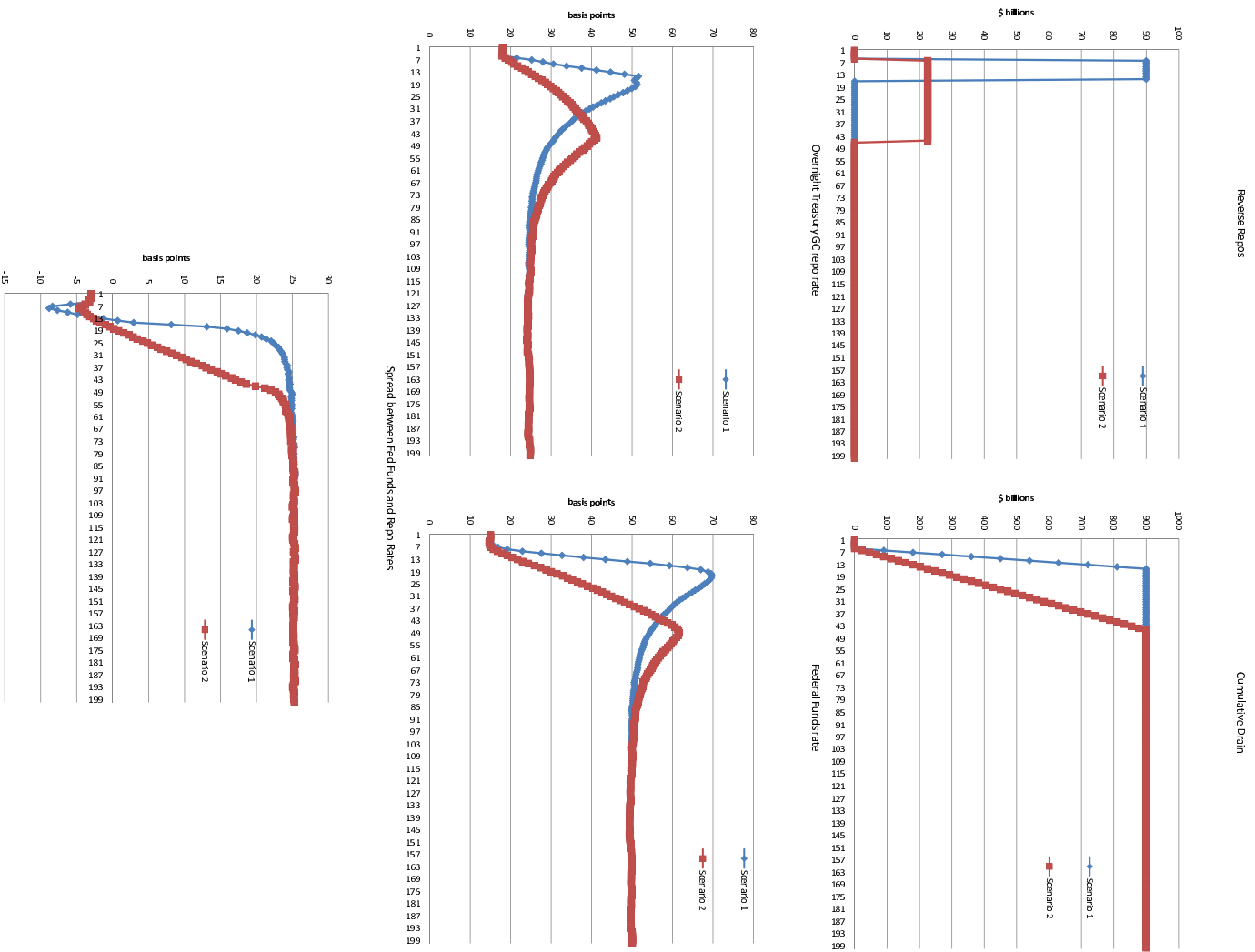
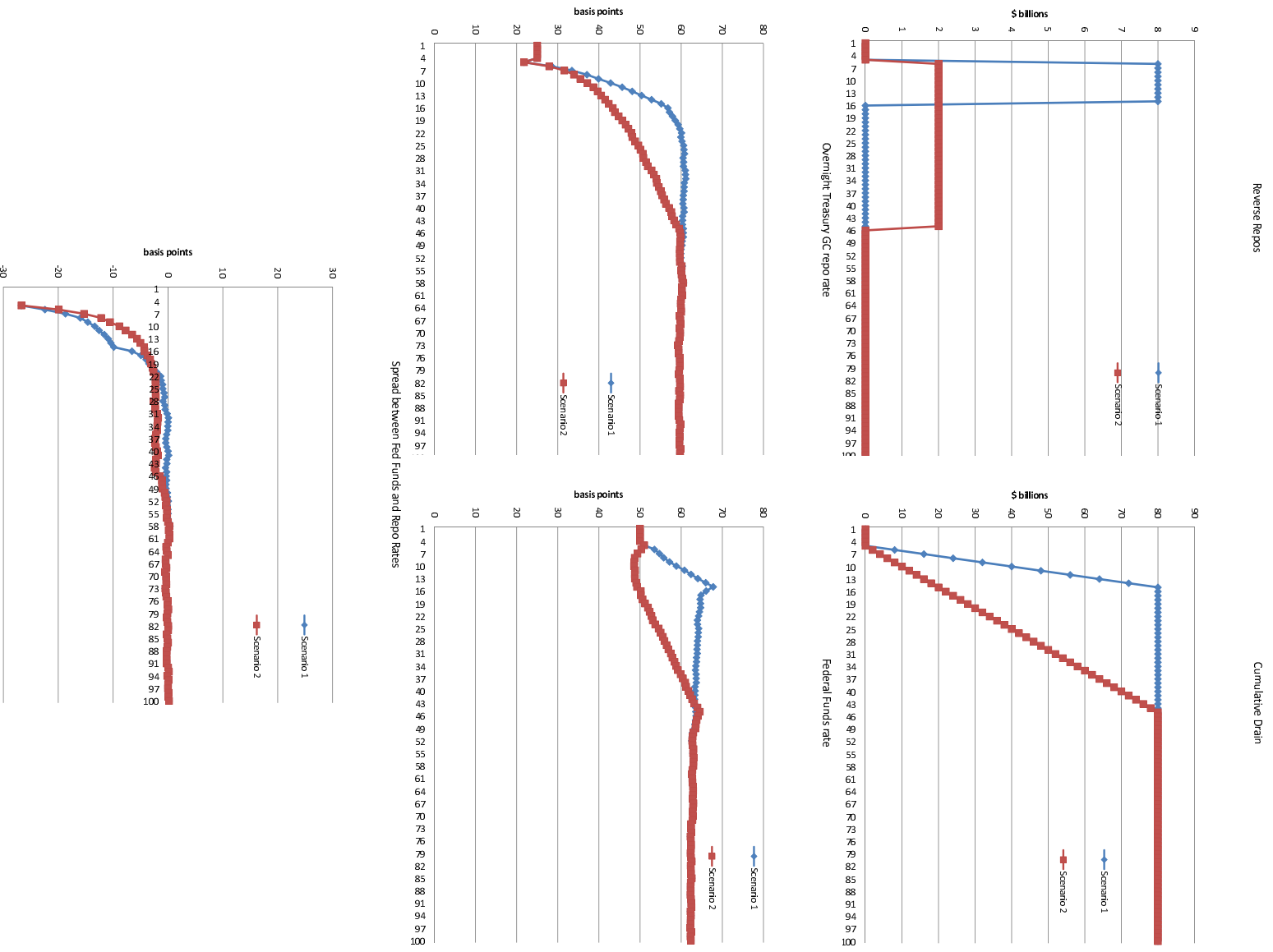


Figure 12: Draining the second \$80 billion





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**Table 1: Augmented Dickey-Fuller tests**

	Federal funds	Repo	N
January 2002 - August 2007	1.054	1.068	1399
	10	6	
August 2007 - December 2008	-0.769	2.345	331
	3	1	
December 2008 - June 2010	-6.513**	-5.076**	385
	2	1	

Lag length below test statistic.

\*\* Reject hypothesis of a unit root at the 5 percent confidence level.

**Table 2: Johansen cointegration tests: federal funds and repo**

Series/No. of eq.	Eigenvalue	Trace stat.	C	Prob > C
<b>January 2002 - August 2007</b>				
None	0.083	123.102	15.495	0.000
At most 1	0.001	0.775	3.841	0.379
<b>August 2007 - December 2008</b>				
None	0.101	34.134	20.262	0.000
At most 1	0.021	5.690	9.165	0.216

**Table 3: Granger causality tests**

Excluded rate	$\chi^2$	DF	Prob.
January 2002 - August 2007			
Repo rate	20.378	3	0.000
Federal funds rate	2.305	3	0.512
August 2007 - August 2008			
Repo rate	4.176	3	0.243
Federal funds rate	1.300	3	0.729
September 2008 - June 2010			
Repo rate	15.313	3	0.002
Federal funds rate	44.410	3	0.000

**Table 4: Results highlights**

<b>Estimation results</b>			
Sample periods	Jan. 2002 - Aug. 2007	Aug. 2007 - Dec. 2008	Dec. 2008 - Jun. 2010
Econometric model	VEC/GARCH	VEC/GARCH	VAR/GARCH
<b>Cointegrating vector</b>			
Constant	-1.913	-18.327	NA
Slope	0.987	0.962	NA
<b>Dynamic equation</b>			
<b>Repo equation</b>			
Speed of adjustment	-0.209	-0.174	NA
Factor miss	NS	0.148	NA
Net issuance	0.049	0.254	0.047
Lag of net issuance	NS	0.094	0.015
LSAP	NA	NA	NS
TGA	NA	NA	-0.005
R <sup>2</sup>	0.327	0.260	0.858
DW	2.193	1.764	2.117
<b>Dynamic equation</b>			
<b>Fed funds equation</b>			
Speed of adjustment	0.066	0.017	NA
Factor miss	-0.520	NS	NA
Net issuance	NS	NS	NS
Lag of net issuance	NS	NS	-0.014
LSAP	NA	NA	-0.042
TGA	NA	NA	0.011
R <sup>2</sup>	0.328	0.114	0.712
DW	1.938	2.233	2.286
<hr/>			
Number of observations	1410	330	385
<b>Total balances</b>			
Median, \$ billions	20	17	913
Range, \$ billions	10...44	9...660	598...1249

Table 5: Normal times: January 2002-August 2007

	Treasury GC Repo			Federal funds		
	Coefficient	Std. error	Z-stat	Coefficient	Std. error	Z-stat
Cointegrating term	-0.209	0.040	-5.204	0.066	0.027	2.477
D(repo(-1))	-0.183	0.112	-1.632	-0.144	0.051	-2.839
D(repo(-2))	-0.101	0.072	-1.389	-0.062	0.070	-0.888
D(repo(-3))	-0.059	0.060	-0.987	-0.037	0.049	-0.754
D(ffeff(-1))	0.027	0.109	0.246	-0.210	0.054	-3.896
D(ffeff(-2))	0.021	0.109	0.196	-0.152	0.069	-2.214
D(ffeff(-3))	0.014	0.064	0.226	-0.093	0.039	-2.389
MP day 1	1.455	2.023	0.719	-0.467	2.682	-0.174
MP day 2	-1.814	1.833	-0.989	-4.355	2.450	-1.778
MP day 5	1.518	2.020	0.751	-0.689	2.068	-0.333
MP day 6	-0.619	1.692	-0.366	-3.121	2.694	-1.158
MP day 7	-0.108	1.462	-0.074	-2.435	2.614	-0.931
MP day 8	0.796	1.650	0.483	-0.742	2.606	-0.285
MP day 9	-0.483	2.657	-0.182	-2.914	2.597	-1.122
MP day 12	1.356	1.829	0.741	-1.141	2.591	-0.440
MP day 13	-1.288	1.899	-0.678	-5.991	2.652	-2.259
MP day 14	-0.540	1.747	-0.309	-2.240	2.593	-0.864
Mid-month	4.641	1.626	2.854	4.765	0.702	6.786
Month-end	2.782	1.527	1.821	3.495	0.531	6.579
25th of month	0.769	0.849	0.906	4.177	0.554	7.535
Quarter-end	-5.868	30.265	-0.194	11.061	3.082	3.589
Year-end	1.284	11.625	0.110	-11.630	12.070	-0.964
D(target)	7.063	12.992	0.544	9.839	27.003	0.364
D(fedfundsvol)	0.055	0.103	0.531	0.097	0.043	2.228
Factor miss	-0.056	0.166	-0.338	-0.520	0.176	-2.950
D(num sellers)	0.006	0.004	1.593	-0.004	0.008	-0.508
D(GSE funds sold)	-0.100	0.033	-3.031	-0.076	0.031	-2.453
D(Libor-OIS)	0.047	0.123	0.386	-0.050	0.217	-0.229
D(Risk-weighted capital ratio)	5.271	43.419	0.121	13.886	15.924	0.872
D(Treasury repo fails)	-0.010	0.017	-0.573	-0.001	0.013	-0.095
Net Treasury issuance	0.049	0.016	3.077	0.012	0.013	0.910
Net Treasury issuance (-1)	0.017	0.032	0.520	-0.020	0.017	-1.170
Overnight securities lending	-0.010	0.055	-0.174	-0.029	0.075	-0.381
Yield curve slope	0.043	0.044	0.978	-0.123	0.042	-2.932
Dealer book	0.114	0.816	0.140	0.163	0.544	0.299
R-squared	0.344			0.344		
Durbin-Watson	2.190			1.940		
N	1406					

Table 6: Crisis: August 2007-December 2008

	Treasury GC Repo			Federal funds		
	Coefficient	Std. error	Z-stat	Coefficient	Std. error	Z-stat
Cointegrating term	-0.174	0.042	-4.130	0.017	0.004	3.910
D(repo(-1))	0.002	0.000	4.991	-0.020	0.022	-0.886
D(repo(-2))	-0.124	0.028	-4.383	-0.020	0.022	-0.914
D(repo(-3))	-0.046	0.011	-4.188	-0.036	0.021	-1.675
D(ffeff(-1))	0.001	0.001	1.780	0.043	0.066	0.641
D(ffeff(-2))	0.213	0.047	4.560	-0.164	0.060	-2.717
D(ffeff(-3))	0.085	0.014	5.875	-0.010	0.008	-1.236
MP day 1	-195.965	9.962	-19.672	-110.829	22.571	-4.910
MP day 2	-193.780	10.355	-18.713	-117.944	23.252	-5.072
MP day 5	-197.850	10.271	-19.264	-114.153	22.412	-5.093
MP day 6	-201.373	10.928	-18.426	-119.850	23.381	-5.126
MP day 7	-198.730	10.658	-18.645	-114.418	23.044	-4.965
MP day 8	-195.960	10.200	-19.212	-116.035	22.737	-5.103
MP day 9	-201.699	10.463	-19.277	-118.813	22.640	-5.248
MP day 12	-195.441	10.432	-18.735	-116.076	22.544	-5.149
MP day 13	-200.911	10.442	-19.241	-115.950	22.638	-5.122
MP day 14	-200.320	10.461	-19.149	-113.370	22.417	-5.057
Mid-month	-1.610	0.089	-18.173	-0.305	0.058	-5.225
Month-end	-4.256	5.617	-0.758	4.783	4.129	1.158
25th of month	-6.483	3.104	-2.089	10.998	2.691	4.087
Quarter-end	-37.413	7.472	-5.007	20.618	8.510	2.423
Year-end	-133.001	7.438	-17.882	-83.991	15.468	-5.430
D(target)	1.031	0.053	19.291	0.538	0.083	6.510
D(fedfundsvol)	-0.118	0.009	-13.067	0.047	0.016	3.055
Factor miss	0.148	0.069	2.138	0.018	0.109	0.165
D(num sellers)	0.089	0.040	2.203	-0.082	0.043	-1.917
D(GSE funds sold)	-0.159	0.075	-2.108	0.120	0.076	1.576
D(Libor-OIS)	-0.373	0.160	-2.326	0.241	0.112	2.146
D(Risk-weighted capital ratio)	145.527	27.802	5.234	-182.964	64.606	-2.832
D(Treasury repo fails)	0.033	0.006	5.888	-0.004	0.003	-1.231
Net Treasury issuance	0.254	0.065	3.916	0.049	0.045	1.098
Net Treasury issuance (-1)	0.094	0.014	6.632	0.062	0.041	1.504
Overnight securities lending	0.130	0.055	2.361	0.164	0.250	0.656
Yield curve slope	-0.028	0.075	-0.381	-0.177	0.119	-1.486
Dealer book	5.115	1.619	3.158	2.118	1.008	2.101
R-squared	0.334			0.205		
Durbin-Watson	1.764			2.233		
N	330					

Table 7: Extended period: December 2008-June 2010

	Treasury GC Repo			Federal funds		
	Coefficient	Std. error	Z-stat	Coefficient	Std. error	Z-stat
D(repo(-1))	0.626	0.000	373372.400	0.120	0.060	2.008
D(repo(-2))	0.026	0.002	10.541	-0.015	0.073	-0.206
D(repo(-3))	0.158	0.004	43.853	0.134	0.058	2.313
D(ffeff(-1))	0.472	0.005	93.807	1.052	0.108	9.731
D(ffeff(-2))	0.035	0.003	10.181	-0.414	0.128	-3.226
D(ffeff(-3))	-0.346	0.005	-70.990	0.043	0.106	0.403
MP day 1	1.008	0.044	22.807	0.426	0.897	0.475
MP day 2	-0.679	0.034	-20.233	0.237	0.709	0.335
MP day 5	0.046	0.038	1.228	1.205	0.646	1.867
MP day 6	-1.824	0.032	-56.810	0.245	0.544	0.450
MP day 7	-2.025	0.024	-84.555	-0.193	0.676	-0.285
MP day 8	0.112	0.054	2.050	-0.995	0.700	-1.420
MP day 9	-0.149	0.131	-1.142	0.353	0.670	0.527
MP day 12	-0.685	0.026	-26.480	0.971	0.781	1.243
MP day 13	-1.729	0.025	-68.608	-0.050	0.581	-0.087
MP day 14	-1.388	0.030	-46.484	0.657	0.543	1.211
Mid-month	1.780	0.087	20.550	1.172	0.861	1.362
Month-end	0.001	0.130	0.004	1.879	0.942	1.996
25th of month	-0.713	0.031	-22.770	-0.585	0.828	-0.706
Quarter-end	-9.150	0.730	-12.535	-2.145	1.324	-1.621
D(fedfundsvol)	-0.019	0.002	-10.789	-0.071	0.018	-3.921
D(num sellers)	0.014	0.001	13.083	-0.003	0.020	-0.142
D(GSE funds sold)	-0.012	0.002	-7.854	0.073	0.012	6.240
D(Libor-OIS)	-0.094	0.004	-21.941	-0.102	0.083	-1.238
D(Risk-weighted capital ratio)	23.221	1.243	18.677	1.006	4.018	0.250
D(Treasury repo fails)	0.049	0.003	14.149	0.019	0.025	0.765
Net Treasury issuance	0.047	0.001	45.118	0.001	0.009	0.131
Net Treasury issuance (-1)	0.015	0.000	53.871	-0.014	0.008	-1.734
Overnight securities lending	0.025	0.007	3.515	0.059	0.082	0.714
Yield curve slope	0.024	0.002	12.394	0.008	0.028	0.288
Dealer book	0.650	0.046	14.249	-0.016	0.243	-0.068
D(LSAP)	-0.002	0.001	-1.502	-0.042	0.008	-5.216
TGA	-0.005	0.000	-21.887	0.011	0.004	2.502
R-squared	0.858			0.712		
Durbin-Watson	2.117			2.286		
N	385					



Figure 13

**Before a Large-Scale Reverse Repo**

Federal Reserve, \$ bill.			
SOMA	2,500	Res. Bal.	1,500
		Rev. Repo	-
		Currency	1,000
	2,500		2,500

Commercial Banks, \$ bill.			
Res. Bal.	1,500	D/MF Dep.	600
Loans	6,700	Oth. Dep.	7,000
		Equity	600
	8,200		8,200

Dealers/Mutual Funds, \$ bill.			
Bank Dep.	600	Repo	-
Rev. Repo	-	Debt	9,450
Sec. Hold.	9,500	Equity	650
	10,100		10,100

**After a Large-Scale Reverse Repo: First Round Effects**

Federal Reserve, \$ bill.			
SOMA	2,500	Res. Bal.	1,000
		Rev. Repo	500
		Currency	1,000
	2,500		2,500

Commercial Banks, \$ bill.			
Res. Bal.	1,000	D/MF Dep.	100
Loans	6,700	Oth. Dep.	7,000
		Equity	600
	7,700		7,700

Dealers/Mutual Funds, \$ bill.			
Bank Dep.	100	Repo	-
Rev. Repo	500	Debt	9,450
Sec. Hold.	9,500	Equity	650
	10,100		10,100

Figure 14

**After a Large-Scale Reverse Repo: First Round Effects**

Federal Reserve, \$ bill.			
SOMA	2,500	Res. Bal.	1,000
		Rev. Repo	500
		Currency	1,000
	2,500		2,500

Commercial Banks, \$ bill.			
Res. Bal.	1,000	D/MF Dep.	100
Loans	6,700	Oth. Dep.	7,000
		Equity	600
	7,700		7,700

Dealers/Mutual Funds, \$ bill.			
Bank Dep.	100	Repo	-
Rev. Repo	500	Debt	9,450
Sec. Hold.	9,500	Equity	650
	10,100		10,100

**After a Large-Scale Reverse Repo: Second Round Effects**

Federal Reserve, \$ bill.			
SOMA	2,500	Res. Bal.	1,000
		Rev. Repo	500
		Currency	1,000
	2,500		2,500

Commercial Banks, \$ bill.			
Res. Bal.	1,000	D/MF Dep.	500
Loans	6,700	Oth. Dep.	6,600
New Loans	500	New Dep.	500
		Equity	600
	8,200		8,200

Dealers/Mutual Funds, \$ bill.			
Bank Dep.	500	Repo	300
Rev. Repo	500	Debt	9,450
Sec. Hold.	9,400	Equity	650
	10,400		10,400