Collateral Values by Asset Class: Evidence from Primary Securities Dealers

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Using data on repurchase agreements by primary securities dealers, we show that three classes of securities (Treasury securities, securities issued by government-sponsored agencies, and mortgage-backed securities) can be formally ranked in terms of their collateral values in the *general collateral* (GC) market. We then show that GC repurchase agreement (repo) spreads across asset classes display jumps and significant temporal variation, especially at times of predictable liquidity needs, consistent with the "safe haven" properties of Treasury securities: *These jumps are driven almost entirely by the behavior of the GC repo rates of Treasury securities*. Estimating the "collateral rents" earned by owners of these securities, we find such rents to be sizable for Treasury securities and nearly zero for agency and mortgage-backed securities. Finally, we link collateral values to asset prices in a simple no-arbitrage framework and show that variations in collateral values explain a significant fraction of changes in short-term yield spreads but *not* those of longer-term spreads. Our results point to securities' role as collateral as a promising direction of research to improve understanding of the pricing of money market securities and their spreads. (*JEL* G12, G23)

Introduction

Financial securities derive their value from two sources: First and perhaps the most important source of value is the promised cash flows by the issuer. We will refer to this source as the value derived from "cash flow rights." The

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second source of value is the ability of the security to serve as collateral. We will refer to this source as value derived from "collateral rights."[1]

Different classes of assets differ in these two sources of value. For example, Treasury securities have relatively high cash flow rights compared with other securities, given the high degree of certainty about future payment flows. Treasury securities as a class are also regarded by market participants as having excellent collateral rights. The relative homogeneity of Treasury securities, active secondary markets, absence of contractual complications such as prepayments, and large issue sizes all contribute to their relatively high collateral value. Other types of financial instruments such as common stocks with small capitalization, as a class, are viewed as securities with relatively poor collateral rights. These characteristics, in addition to the certainty of future payment flows, contribute to the widespread acceptance of Treasury securities as collateral, and enable institutions that borrow cash by posting these securities as collateral to enjoy lower borrowing rates. Investors that would take possession of such securities in the event of default could expect either to be able to liquidate their holdings with relative ease at minimal loss (given active secondary markets), or to be able to borrow money more readily posting these securities as collateral.

The distribution of the value of a security between these two sources may vary over time for a number of reasons: In periods of borrowing constraints and aggregate liquidity shocks, it is reasonable to expect the collateral rights of Treasury securities, as a class, to command a higher valuation. Likewise, in periods of abundant liquidity we may expect the collateral rights to be of less value. In periods of aggregate financial distress, there may be a strong preference to hold securities whose cash flow rights are not subject to default. Since such crises are usually also accompanied by insufficient access to credit, the value of collateral rights may also go up. Hence, we may expect to see a positive association between measures of collateral rights and the market value of the securities. Furthermore, this correlation should be especially high in periods of aggregate liquidity shocks.

The goal of this article is to examine the time-series and cross-sectional properties of collateral rights of three distinct asset classes: Treasury, federal agency debt securities, and agency mortgage-backed securities (MBSs).[2] Specifically, we are the first to estimate the relative collateral values of different classes of securities (measured by the GC repurchase agreement [known as *repo*] rate spreads) and their collateral rents (measured by the secured-unsecured rate spreads). In addition, we explore the extent to which differences in the valuation of collateral rights may help explain the differences in

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1 Securities such as common stock will also have "control rights." We consider in our article only debt securities for which control rights are unimportant.

2 The term MBS is used in the article to refer to agency mortgage-backed securities to the exclusion of private-label MBSs.

the overall valuation of these asset classes. We briefly motivate these questions further below.

According to data from the Securities Industry and Financial Markets Association (SIFMA), the securities dealers held on average \$3.91 trillion of securities under repo and \$2.59 trillion of cash under reverse repo arrangements in the fourth quarter of 2008. As shown in Table 1, primary dealers, for which more detailed data are available, rely especially heavily on repurchase agreements, favoring Treasury securities over agency and mortgage-backed securities both in overnight and in term contracts.[3] This dominance of Treasury repo transactions over agency and mortgage-backed securities should be viewed in the context of the size of these underlying markets: The Securities Industry and Financial Markets Association (2009) reports that the size of the Treasury market as of the fourth quarter of 2008 was \$6.1 trillion, whereas the federal agency securities market was \$3.2 trillion, and the MBS market stood at \$8.9 trillion. As a proportion of the underlying market, repo financing in the Treasury market far exceeds the other markets. This may be driven by many of

Table 1
Financing by Primary Securities Dealers (in billions of \$)

Securities in	January 2007	December 2007	August 2008
U.S. Treasury			
Overnight and continuing	1,280	1,471	1,467
Term	1,105	1,302	1,352
Federal agency and GSEs			
Overnight and continuing	177	219	261
Term	231	262	327
Mortgage-backed			
Overnight and continuing	140	172	193
Term	406	460	425
Corporate			
Overnight and continuing	107	128	124
Term	91	85	60
Securities out	**January 2007**	**December 2007**	**August 2008**
U.S. Treasury			
Overnight and continuing	1,277	1,425	1,450
Term	874	1,190	1,150
Federal agency and GSEs			
Overnight and continuing	320	399	485
Term	145	158	222
Mortgage-backed			
Overnight and continuing	604	784	786
Term	225	250	202
Corporate			
Overnight and continuing	302	363	304
Term	77	89	75

Federal Reserve Bulletin, Statistical Supplement, Jun 2007, Mar 2008, Dec 2008. GSE = Government Sponsored Enterprise.

3 Data are from Staff Publications Committee (2009). Primary dealers are designated counterparties to the Fed's open market operations. The current list of primary dealers is available at www.newyorkfed.org/markets/pridealers_current.html.

the same factors that lead market participants to regard Treasury securities as having excellent collateral rights.

Relevant Literature

One of the key themes in recent research on the role of collateral in the funding of financial intermediaries has been to explain differences between rates on repos against general collateral (GC) (which apply when any security within an asset class can be used as collateral) and "special" repo rates (which apply when only a specific security can be posted as collateral). One of the first contributions to this line of research is by Cornell and Shapiro (1989), who document the price premium commanded by thirty-year Treasury bonds and show this premium to reflect, largely, low "special" repo rates in 1986. Similarly, Sundaresan (1994) documents that newly issued Treasury securities tend to trade "special" in repo markets, with the extent of specialness reflecting auction cycles. Duffie (1996) shows that the specialness in repo markets should raise the price of the underlying security by the present value of the saving in borrowing costs in repo markets—a prediction supported empirically by Jordan and Jordan (1997). The latter paper also shows that the liquidity premium in newly issued Treasury securities reflects their specialness in repo markets, with auction tightness and percentage awarded to dealers also helping explain subsequent specialness in repo markets. More recently, Krishnamurthy (2002) documents the spread between newly issued and old thirty-year Treasury bonds, also linking this spread to the difference in repo market financing rates between the two bonds.[4] Longstaff (2004) has shown that Treasury securities have a significant "flight to liquidity" premium built into their market valuation. He demonstrates this by first estimating the spread between Treasury bonds and otherwise similar bonds issued by Refco Inc. (Chicago, Illinois), and then showing that this spread may be as much as 15% of the value of the Treasury securities. He further examines the determinants of this spread. Our study complements the paper of Longstaff (2004) by showing that in episodes of flight to quality and liquidity, Treasury GC repo rates fall well below the GC rates of other asset classes, thereby contributing further to their increased value.

The role played by securities as collateral and their pricing implications have been stressed by Brunnermeir and Pedersen (2009), Garleanu and Pedersen (2009), and Geanakaplos (1997, 2003, 2009). Brunnermeir and Pedersen (2009) note that securities with identical cash flows can have substantially different margins due to differences in their current and potential secondary market liquidity. Garleanu and Pedersen (2009) argue that the equilibrium pricing of securities must reflect both their betas and their margins. In a series of

[4] Two papers, by Bindseil, Nyborg, and Strebulaev (2002, 2009), explore related issues using data on repos against the European Central Bank. However, the focus of these papers is less on estimating collateral values, and more on auction-related themes, including bidding strategies and auction performance.

papers, Geanakaplos has explored the collateral values of securities and their implications for default, leverage, and pricing. In Geanakaplos (2009), supply and demand determines both the equilibrium price (interest rates) and margins (collateral value). The basic idea that margins are endogenous has been developed in Geanakaplos (1997, 2003). These papers provide a theoretical background and underpinning to some of our empirical results.

Contributions and Summary of Results

A common feature of the extant literature in this area is its reliance on repo rates drawn from the inter-dealer market for Treasury repos and—more importantly—its emphasis on spreads between rates on general and special Treasury collateral. To our knowledge, rate spreads between repos on GC for different classes of securities have not yet been investigated. There are many reasons why the study of the financing rates across different asset classes is of interest. First, such an examination is valuable in as much as such an empirical study can help us understand how financing rates of different asset classes vary over time and what factors may influence such time variation. In addition, the relative values of different classes of collateral are likely to vary in ways that shed light on the determinants of collateral values, such as financial intermediaries' needs for liquidity, the need for cash investors to have liquid collateral, and the extent of the demand in the market for protection ("safe haven") against aggregate liquidity shocks. Finally, any variations in financing rates (over time and across asset classes) may have implications for asset pricing. For these reasons, in this article we undertake a comprehensive study of the longitudinal and cross-collateral properties of rates for GC repos, drawing on a newly available set of data on primary dealers' repo activity provided by the Federal Reserve Bank of New York. These data contain information on the secured funding activities of primary securities dealers, including data on financing rates over a narrow daily window (the first hour of trading) for three different classes of collateral: Treasury, agency, and mortgage-backed securities. These data allow us to make contributions to the repo literature in several directions.

First, we compare rates on repos against Treasury securities with rates on repos against agency and mortgage-backed securities, in order to evaluate differences in collateral values across the three asset classes. We find that Treasury repo rates are significantly (economically and statistically) lower than those of the other two asset classes. In our estimation (using data spanning our sample period of over seven years), the long-run average repo spreads between agency and Treasury securities is 5.2 basis points, while that between mortgage-backed and Treasury securities is 6.1 basis points. The data in our sample cover the period from October 1999 to December 2006, and hence do not include the period of credit crisis. Economic intuition would suggest that during the crisis period, this effect should be much bigger. Indeed, during the crisis, there were extended periods during which the GC repo rates of Treasury were lower than the MBS GC repo rates by 100–300 basis points.[5]

Second, we document significant time-variation in the GC repo spreads, which often exhibit jumps around predictable liquidity dates (such as year-ends, quarter-ends, holidays, etc.) and random aggregate shocks. We use an estimation procedure to account for the possibility of jumps in repo spreads around predictable liquidity dates and random aggregate shocks and find that rates on GC repos against Treasury collateral decline sharply relative to rates on GC repos against agency and mortgage-backed securities in periods of liquidity needs. This evidence is consistent with the view that Treasury securities incorporate a safe-haven premium relative to other securities. *Our evidence finds little or no increase in the GC repo rates of agency securities and MBS collateral relative to unsecured rates around such dates*. This is an important finding, as any evidence of such an increase would have suggested that the increase in GC repo spreads might be due to the perceived increase in credit risk of the agency and mortgage-backed securities relative to the Treasury as a class.[6]

Third, we extract collateral values of Treasury, federal agency, and mortgage-backed securities by calculating spreads between rates on GC repos for these securities and matching rates on unsecured loans (federal funds rates) and study their dynamic properties. Consistent with the theoretical prior that owners of securities can borrow funds at a lower rate when pledging such securities as collateral, we document that Treasury securities display superior attributes as collateral and therefore command greater “collateral rents” by way of lower repo rates relative to the fed funds rate. Somewhat surprisingly, we find that repo rates against agency and mortage-backed securities are not meaningfully different from rates on unsecured loans, a finding that suggests that agency and mortgage-backed securities are used by their owners to obtain (or expand) access to the short-term money market rather than to gain financing price advantages.

Finally, we develop a simple no-arbitrage relationship between the repo spreads of assets and their yield spreads. Our model predicts that yield spreads should capture the present value of the stream of future repo spreads. Using our estimated parameters, we evaluate the predictions of our model. Consistent with the view that in an efficient market the desirability of a security as a collateral should be fully incorporated in its price,[7] we find that repo spreads help explain a significant percentage of the yield spreads for short (money market) maturities. However, we find GC repo spreads to play a negligible role in determining longer-term yield spreads.

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5 Data confirming this can be found in the Markets Group of the Federal Reserve Bank of New York (2009) publication concerning the open market operations of 2008.

6 We thank the referee for alerting us to this potential alternative explanation.

7 For detailed analysis, in the context of Treasury securities, see Duffie (1996).

The article is organized as follows. Section 1 reviews the market for repurchase agreements against general collateral. Section 2 explains the data used in our study and presents summary statistics and preliminary empirical evidence. Section 3 formulates our formal empirical model of collateral spreads and values, discusses its estimation, and presents our main findings. Section 4 links collateral values to pricing spreads through a simple arbitrage argument and verifies the empirical relevance of such a link. Section 5 concludes.

1. The Market for General Collateral Repo

The term “repurchase agreement” identifies a transaction in which an investor (the “repo borrower”of cash) acquires funds by selling securities to another investor (the “repo lender”of cash), simultaneously agreeing to repurchase those securities at a future time at a specified price, where the excess over the initial sale price reflects the interest on the loan.[8] Albeit technically defined as purchases and matched forward sales of securities, for most practical purposes repos can be thought of as collateralized loans. Certain features of repo agreements do indeed confirm this analogy, such as the practice of assigning any coupon that might be payable during the term of the repo (along with full accrual of interest) to the repo borrower (i.e., to the original owner of the security) rather than to the repo lender (the temporary owner of the security). Other features of repo contracts, however, align repos more closely to securities sales, such as the right acquired by repo lenders to immediately liquidate the collateral in case of default on the underlying loan.

GC repos differ from “special collateral” repos in that for the latter case, a specific security is designated as the only acceptable collateral, whereas with GC repos, a certain designated class of securities are acceptable. The cash borrower has the option to deliver as collateral any securities that fall within that class. Borrowers of cash in the GC repo market are often financing a portfolio of securities, while lenders of cash are looking for a safe investment that offers market-based rates of return. Indeed, the market for GC repos has grown into one of the main channels for funding of U.S. financial institutions in recent years and short-term lending of excess cash balances. GC repos typically carry a short maturity. Most are arranged with terms of one to a few days, or standard terms of one, two, or three weeks, or one, two, three, or six months.[9] Dollar amounts tend to be large, usually exceeding $25 million per trade for short maturities and $10 million for longer-term repos.

8 Whether a specific transaction is termed a repo or a reverse repo usually depends on the perspective of the borrower or lender of the cash or securities. For the borrower of cash (lender of securities) these transactions are called “repos,” and “reverse repos” for the lender of cash (borrower of securities).

9 While most repos are standardized along these lines, “open” repos (i.e, open-ended, multi-day contracts) are also traded, as well as “continuing” repos that are renewed each day upon agreement by both parties, allowing for adjustment in both the repo rate and the amount of funds invested.

A key distinction in GC repo transactions hinges on the type of collateral underlying the transaction. The class of acceptable collateral may include all Treasury securities or certain private sector securities, or it could be restricted to a subset of such securities, such as those maturing in less than ten years. In practice, Treasury securities account for a large share of this market, but there is a very active market also for repos against securities issued by government-sponsored agencies and agency mortgage-backed securities. The very short-term nature of the GC repo data (overnight) and the admissibility of a designated class of securities allows us to shed some light on the differences in collateral value of different asset classes.

Different settlement procedures tend to dominate different segments of the GC repo market.[10] The repo data used in this study largely reflect transactions between the Fed's primary dealers and their biggest retail customers, such as money market mutual funds and other large institutional investors that have considerable quantities of cash to invest each day. In this segment of the market, "tri-party" agreements are typically used to settle GC repo transactions, for which both the (cash) borrower and lender maintain a securities account and a deposit account at a clearing bank.[11] When a tri-party repo transaction first settles (or unwinds), the clearing bank will move funds and securities between the respective cash and custody accounts of the borrower and lender. Clearing banks also provide other services, such as valuation of collateral.

GC repo transactions are not necessarily risk free, even if the cash flow of the underlying security is free of default risk. Specifically, if the (cash) borrower fails to repurchase the securities at term, in which case the (cash) lender keeps the security, the lender is exposed to the risk of a change in the security's value due to market movements as well as the risk of being unable to liquidate the securities as needed. To mitigate the risk that the (cash) borrower fails to return the funds, repos are normally over-collateralized, by requiring the market value of the underlying collateral to exceed the amount of the loan, and they are subject to daily mark-to-market margining. The over-collateralization factor ("haircut") normally depends on the term of the repo, the liquidity of the underlying security, and the strength of the counterparties involved. Haircuts tend to be larger as the interest sensitivity of the underlying security's price increases—hence, they tend to rise with the term to maturity of the underlying securities. They also tend to rise with credit risk—hence, they are higher for private instruments than comparable Treasury securities. Herring and Schuermann (2005) note that "for U.S. government and agency instruments, the haircuts are the most modest. They range from 0 percent for very short-term (0–3 months) to 6 percent for long-term ($>$25 years) debt." With the onset of the credit crisis in August 2007, haircuts have changed, even

10 Detailed descriptions of some of the types of settlement practices used by the primary dealers and recent innovations are found in Fleming and Garbade (2002, 2003).

11 The two largest clearing banks that dominate this business are JPMorgan Chase and Bank of New York.

for Treasury securities. Our understanding is that the haircuts have become much higher at times even for federal agency securities relative to Treasuries. Unfortunately, we do not have data for this period.[12]

2. GC Repo Spreads: Data and Summary Evidence

In this section, we briefly describe the sources and nature of our data. We then present some summary evidence on the behavior of GC repo spreads across the three asset classes.

2.1 Data

The core data for our study are the Federal Reserve Bank of New York's daily data on overnight repurchase agreements contracted by Government Securities Primary Dealers with their retail customers between about 8:00 and 8:45 a.m., from October 12, 1999, to December 25, 2006.[13]

The data that we obtained are collected by the Federal Reserve Bank of New York as part of a daily survey of the primary dealers,[14] and include volume-weighted averages of rates paid by all current dealers in the GC repo market with their retail customers, such as money market funds, since the open of business that day, broken down by three classes of general collateral: Treasury securities, securities issued by government-sponsored agencies, and mortgage-backed securities. To our knowledge, the Fed's survey of primary dealers is the only systematic source of data on dollar GC repurchase agreements. This lack of data reflects the fact that—unlike special repos, which trade largely on electronic platforms like BrokerTec—the GC market trades mostly through voice brokers, who tend to keep limited information archived in usable electronic form. A noteworthy feature of our data is that their morning sampling time of retail repo transactions tends to be earlier in the day than when most inter-dealer trades are executed. Nonetheless, rates in these two market segments are closely bound together, as inter-dealer trading in general collateral securities is used to balance mismatches in flows between individual dealers and their retail customers.

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12 When short-term interest rates are very low, there may be an incentive to "fail" in repo transactions. In "Treasury Market Best Practices," the Treasury Market Practices Group (2009) reports that a "fails charge" has been instituted, reducing the incentive to fail.

13 These data are highly confidential and were provided to the authors under tightly controlled circumstances. Regrettably, the data that we obtained did not include the interesting crisis period that began in the summer of 2007. However, it would be of great interest to extend our methodological contribution to a sample inclusive of a major crisis period, should the required data become available in the future.

14 Altogether, 31 different dealers were surveyed over our sample period, with an average of 24 surveyed on any given day. Variability during the sample in the number of surveyed dealers reflects almost entirely changes in the number of eligible dealers, caused by mergers and acquisitions among dealers and a few entries or exits by certain institutions in the pool of primary dealers.

In addition to our key data on repurchase agreements, other data we used include constant-maturity bond rates for Treasury securities (obtained from the Board of Governors of the Federal Reserve) and agency securities (obtained from Fannie Mae). We also obtained series of 9:00 a.m. federal funds rates from the Federal Reserve Bank of New York, and Nelson-Siegel-Svensson discount rates from the Board of Governors of the Federal Reserve (the latter data are discussed in detail by Gurkaynak, Sack, and Wright 2007). Finally, from Michael Fleming and Neel Krishnan at the Federal Reserve Bank of New York, we obtained average daily bid-ask spreads between 8:00 and 9:00 a.m. for the on-the-run two-year note, from January 1, 2001, to February 3, 2006, calculated from transaction-level BrokerTec data.

2.2 Summary Evidence

Summary information on our repo data is displayed in Table 2. The raw data series are shown in Figures 1 and 2, while frequency distributions of the series are plotted in Figures 3 and 4. Much economic intuition can be gained by observing the raw data spreads. The key information displayed in the table consists of raw means and volatilities of spreads between (daily, volume-weighted) rates on repos against different classes of collateral and spreads between unsecured (federal funds) and secured (repo) rates. The highlight of the table is the strict order among the three classes of collateral: When posting Treasury securities as collateral, repo borrowers can obtain financing at rates 6 basis points lower, on average, than when posting agency securities, and at rates 7 points lower than when posting MBSs. The ordering is clearly statistically significant, as the 95% confidence interval for the estimated mean of the Treasury-agency spread is [−6.25, −5.76], while that for the agency-MBS spread is [−1.07, −0.94].

Another feature displayed by our collateral spreads is the excess of mean over median spreads, suggesting a right-tailed distribution that may reflect large spreads during episodes of flight to quality. This conjecture is informally confirmed by the large and asymmetric ranges between highest and lowest spreads around mean spreads displayed in Table 2.

Table 2
Federal Reserve's Dealer Survey: Summary Information

Sample	10/13/1999 – 1/25/ 2006				
# of observations (# business days)	1,562				
Spreads	Mean	Median	Standard deviation	Minimum	Maximum
Treasury repo – Agency repo	−6.00	−4.67	4.87	−78.87	−1.22
Treasury repo – Mortgage-backed repo	−7.01	−5.54	5.68	−97.87	−1.88
Agency repo – Mortgage-backed repo	−1.01	−0.83	1.34	−42.34	1.55
Federal funds – Treasury repo	7.50	5.36	9.94	−4.60	263.45
Federal funds – Agency repo	1.50	0.73	6.86	−25.18	207.92
Federal funds – Mortgage-backed repo	0.49	−0.24	5.98	−29.70	166.58

All spreads are in basis points and computed as differences between daily volume-weighted rates.

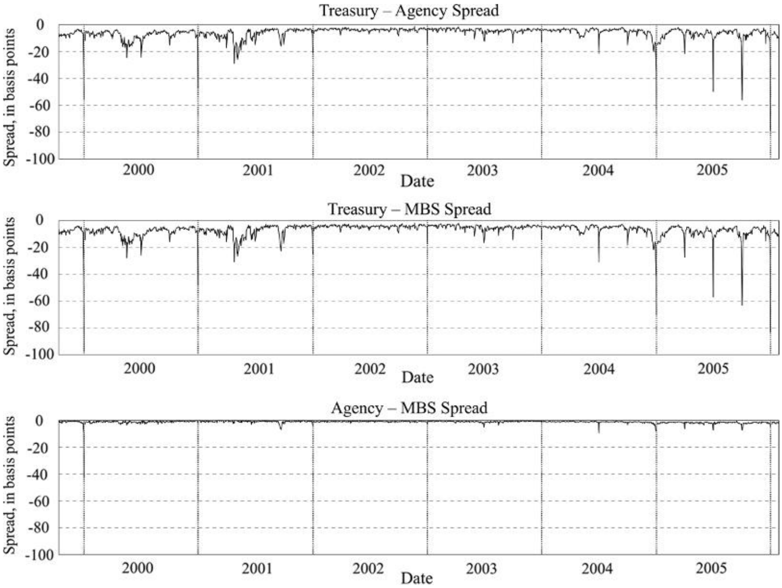

Figure 1
Spreads between repo rates against different collateral

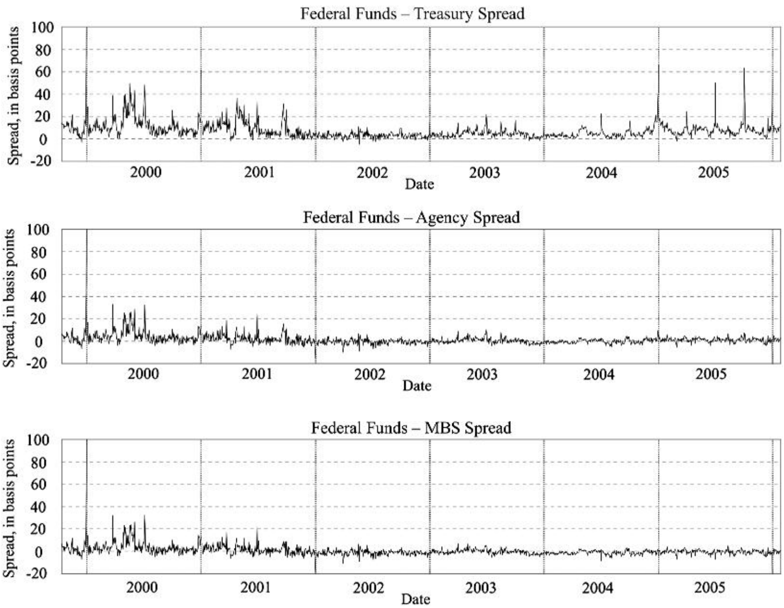

Figure 2
Spreads between unsecured (federal funds) and repo rates

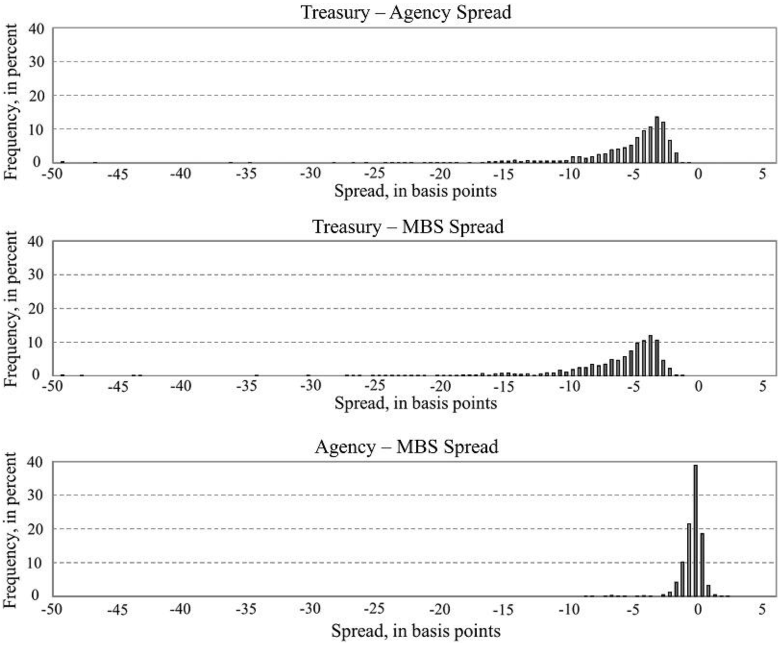

Figure 3
Frequency distributions of spreads between repo rates against different collateral

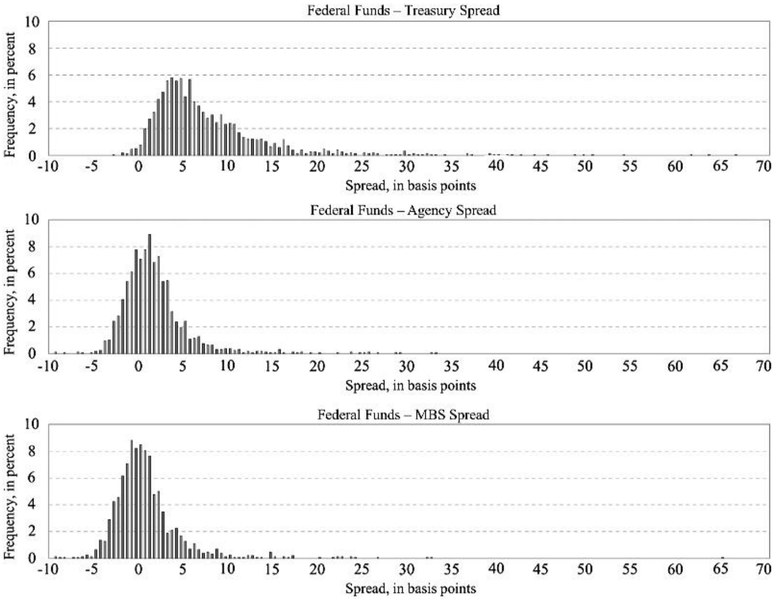

Figure 4
Frequency distributions of spreads between unsecured (federal funds) and repo rates

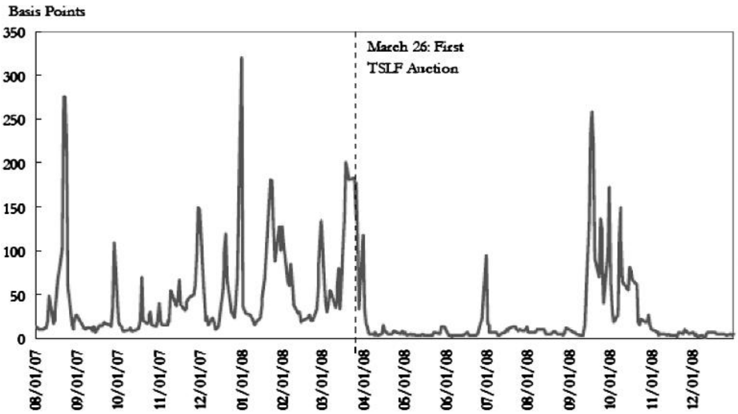

Figure 5
Agency–Treasury overnight financing spread
Source: Chart 28 from the "Domestic Open Market Operations During 2008" publication from the Markets Group of the Federal Reserve Bank of New York (2009).

Our sample does not include the crisis period, but the evidence during the crisis period suggests that the GC repo rates of Treasury were often at a substantial discount to the GC repo rates of MBS. We reproduce in Figure 5 the GC repo spreads, which were often in the range of 100 to 300 basis points. The Fed was actively intervening in the repo markets during this period to exchange mortgage collateral with Treasury collateral.

When measured relative to the unsecured (federal funds) rate, the repo rates for our three classes of collateral display properties similar to those discussed above, with large spreads for repos against Treasury securities and smaller spreads for repos against agency and mortgage-backed securities. An additional, albeit preliminary, piece of information delivered by the examination of raw secured-unsecured spreads is that the large spreads between repo rates against Treasuries and against other securities match roughly the spreads between Treasury repo rates and the federal funds rate: Holders of Treasuries can secure favorable financing relative to the unsecured market rate by posting Treasuries as collateral. By contrast, holders of other securities can obtain only marginally favorable financing when posting such securities as collateral, relative to the unsecured rate.

Altogether, Table 2 offers evidence of ordering among various types of GC repo and uncollateralized short-term rates. The main goal of the next section is a rigorous analysis of the time-series behavior of repo spreads. This will allow us to disentangle its diffusive components from its periodic and stochastic jump components. This analysis will provide a more precise estimate of the collateral value premium across classes, as well as quantify the contribution of jumps, both deterministic and random, to the overall volatility of the spreads.

3. The Empirical Behavior of GC Repo Spreads

3.1 Empirical model

It is well known that money market interest rates and spreads exhibit seasonality. This has been documented by a number of scholars, including Musto (1997) in the context of the rates on commercial paper, and Sundaresan and Wang (2009) in the context of the spreads between repo rates and target fed funds rates. The latter paper shows that the volatility of the spreads is much higher in quarter-ends. Therefore, in this section we specify a process for the evolution of the spreads that allows for the possibility of jumps in the levels of the spreads at predictable dates (such as quarter-ends, holidays, year-ends, etc.) as well as random future dates when there may be an aggregate liquidity shock. In addition, we allow for the possibility of stochastic volatility in the spreads. To this end, we first begin by defining spreads and interpreting their economic meaning.

3.2 Definition of spreads

To investigate the time-series and cross-sectional behavior of repo rates, we define the following set of interest-rate spreads. First, let the repo spreads

$$S_t^{TRE-AGE} \equiv r_t^{TRE} - r_t^{AGE} \tag{1}$$
$$S_t^{TRE-MBS} \equiv r_t^{TRE} - r_t^{MBS} \tag{2}$$
$$S_t^{AGE-MBS} \equiv r_t^{AGE} - r_t^{MBS} \tag{3}$$

denote the spreads between the overnight rates on repurchase agreements against Treasury (*TRE*), agency (*AGE*), and mortgage-backed (*MBS*) securities, respectively.[15]

Second, let the secured-unsecured spreads

$$S_t^{FF-TRE} \equiv r_t^{FF} - r_t^{TRE} \tag{4}$$
$$S_t^{FF-AGE} \equiv r_t^{FF} - r_t^{AGE} \tag{5}$$
$$S_t^{FF-MBS} \equiv r_t^{FF} - r_t^{MBS} \tag{6}$$

denote the spreads between the contemporaneous rate on (unsecured) loans of overnight federal funds and the three repo rates. (As noted above, our federal funds rates were sampled almost contemporaneously to the repo data, with the former capturing conditions just before 9:00 a.m., and the latter capturing conditions at 8:00–8:45 a.m.)

Note that the secured-unsecured spreads effectively measure the "collateral rents" earned by the owners of the relevant security. Intuitively, such owners can post the security as collateral to borrow cash overnight at the current GC

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15 The notation r_t^{TRE} is used to denote the overnight GC repo rate applicable to Treasury collateral, and so on. We use r_t^{FF} to denote the overnight effective fed funds rate.

rate while lending those funds overnight in the unsecured market at the current unsecured rate. Thus, the income earned on this position equals the spread between the secured and unsecured rates or, equivalently, measures the opportunity cost incurred by the security's owner, should he choose to hold on to the security instead of lending it out.

We now wish to specify a process to describe the evolution of spreads. The process should accommodate the following possibilities: First, the process should allow for potential mean reversion. Second, the process should allow for possible jumps in the levels of rates and spreads to occur at predictable future dates (such as quarter-ends), to account for seasonality, as well as random future points when an aggregate shock might occur. Finally, the process should permit the volatility to be stochastic: This is necessary, as the rates and the spreads may display increased volatility at various points in time such as year-ends and quarter-ends. To analyze the empirical behavior of these spreads (both collateral spreads and rents), we estimate the following square-root multi-factor model[16]:

$$dS_t = (\alpha_S + \beta_S S_t)dt + \sqrt{V_t}dz_t^1 + d\left(\sum_{i=1}^{N_t} Z_{\tau_i} + \sum_{j=1}^{11}\sum_{i=1}^{N_t^j} Z^j_{\tau_i^j}\right) \tag{7}$$

$$dV_t = (\alpha_V - (1-\beta_V)V_t)dt + \sigma\sqrt{V_t}dz_t^2\,. \tag{8}$$

In Equation (7), N_t^j is a counting process for jumps occurring at deterministic times in process j, where $j = \{1, \ldots, 11\}$; N_t is a Poisson counting process for arrivals in the random jump process; and $Z^j_{\tau_i^j}$ and Z_{τ_i} are the jump sizes for the deterministic process j and random process, respectively, and are assumed to be normally distributed. Finally, z_t^1 and z_t^2 are Brownian motions, with correlation $corr(z_t^1, z_t^2) = \rho dt$, and α_S, α_V, β_S, and β_V are the drift and autoregressive parameters in the mean and variance equations, respectively. These parameters will shed light on the extent to which the spread levels and the volatility are mean-reverting.

Model (7)–(8) essentially extend the classic model of Heston (1993) by augmenting standard diffusion and heteroscedastic terms with jump factors occurring at both deterministic and random times. We selected a fairly broad set of possible times for the realization of deterministic jumps, inspired by previous evidence on the empirical behavior of money market rates. We included days preceding and following holidays; the fifteenth of each month (or first business day thereafter); the first and last day of each month, of each quarter, and of each year; and the day prior to the last day of each quarter and of each year, for a total of eleven jump factors. Naturally, it will be an empirical matter to determine whether some of these factors are significant.

16 For simplicity, we have abstracted from modeling jumps in volatilities.

3.3 Estimation approach

We estimated Model (7)–(8) using Markov chain Monte Carlo (MCMC) simulation techniques. For details of the properties of MCMC estimation, see Johannes and Polson (2006).[17] In essence, MCMC is used in Bayesian estimation to allow consistent and computationally efficient estimation of complex models such as (7)–(8), and delivers parameter estimates along with their estimated probability distributions. MCMC estimation involves first discretizing the model. (Results in the MCMC literature show that choosing sufficiently short intervals, such as one day, is generally sufficient to eliminate discretization bias.) Second, suitable conjugate prior distributions for the parameters are chosen. (Similarly, standard results ensure that the priors do not matter for estimation results for informative well-behaved likelihood functions.) Third, the high-dimension likelihood function is partitioned into lower-dimension conditional distributions (with standard results, namely, the Clifford-Hammersley Theorem, ensuring that the joint posterior likelihood is completely characterized by its conditional components). Fourth, values are drawn (this is the *Monte Carlo* stage) from the prior distribution using Model (7)–(8). Fifth, Bayesian updating is used to generate posterior distributions for the parameters allowing the draw/update process (fourth and fifth steps) to be replicated iteratively, yielding a *Markov chain* of values for the parameter set. The process is iterated a sufficient number of times (100,000 times, in our case) to secure convergence to the unconditional distribution. The last-iteration posterior conditional distribution provides an estimate of the distribution of the parameter values and can be used for inference. In our case, the estimation delivers at the same time an estimate of the latent volatility process and an estimate of individual jumps.

3.4 Results from estimation

We first present and discuss the results on collateral spreads across asset classes and then turn to an analysis of the collateral rents.

3.4.1 Collateral spreads. Tables 3–5 summarize the estimated behavior of the collateral spreads $S_t^{TRE-AGE}$, $S_t^{TRE-MBS}$, and $S_t^{AGE-MBS}$.

The large number of observations allows us to estimate the parameters of both mean and variance processes with precision. As a preliminary matter, the estimated β_S and β_V coefficients (negative the former, smaller-than-one the latter) imply the stability of the mean and variance processes for all three spreads.

A key role in our analysis is played by the jump factors, estimates of which are shown in the mid-panels of Tables 3–5. Comparing the mean jumps across the three tables reveals a number of stylized facts.

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[17] See Jacquier, Polson, and Rossi (1994) for an example of estimating stochastic volatility models. See Eraker, Johannes, and Polson (2003) for an example of estimating models with jumps in level and volatility.

Table 3
Treasury–Agency Spread Estimation

Diffusion coefficients			Estimates	
α_S			−0.544 (0.044)	
β_S			−0.139 (0.010)	
α_V			0.038 (0.007)	
β_V			0.970 (0.006)	
σ			0.205 (0.026)	
ρ			−0.118 (0.052)	
Jump coefficients	**Mean jump**	**Variance of jump**	**Arrival Intensity**	**Share of estimated variance**
Random jump	−4.416 (2.604)	8.414 (1.269)	0.010 (0.003)	0.090
Before holiday	−0.226 (0.264)	1.602 (0.173)	–	0.014
After holiday	−0.167 (0.261)	1.579 (0.69)	–	0.014
15th	−0.649 (0.226)	1.568 (0.162)	–	0.015
First day of month	0.975 (0.300)	1.781 (0.203)	–	0.020
Month end	−1.579 (0.308)	1.856 (0.211)	–	0.022
Before quarter end	−1.342 (0.728)	2.969 (0.596)	–	0.018
Quarter end	−7.194 (2.103)	11.915 (2.106)	–	0.297
After quarter end	5.769 (1.991)	10.953 (2.854)	–	0.251
Before year end	−3.283 (2.070)	5.859 (1.678)	–	0.020
Year end	−4.701 (2.814)	5.347 (2.959)	–	0.017
After year end	4.851 (3.060)	9.785 (6.664)	–	0.056
All jumps				0.832
Long run mean spreads			−5.176 (0.448)	
95% confidence interval:			[−5.92, −4.44]	
99% confidence interval:			[−6.25, −4.14]	

The table reports results of MCMC estimation of the model. Standard errors are reported in parentheses, and are computed from the estimated posterior distribution of the coefficients. The sample includes 1,562 daily observations from October 13, 1999, to January 25, 2006.

Table 4
Treasury–MBS Spread Estimation

Diffusion coefficients			Estimates	
α_S			−0.606 (0.061)	
β_S			−0.132 (0.011)	
α_V			0.058 (0.040)	
β_V			0.969 (0.008)	
σ			0.225 (0.041)	
ρ			−0.123 (0.052)	
Jump coefficients	**Mean jump**	**Variance of jump**	**Arrival Intensity**	**Share of estimated variance**
Random jump	−5.472 (3.814)	10.286 (1.604)	0.009 (0.004)	0.087
Before holiday	−0.161 (0.313)	1.849 (0.218)	–	0.012
After holiday	−0.296 (0.315)	1.854 (0.210)	–	0.013
15th	−0.827 (0.270)	1.824 (0.194)	–	0.014
First day of month	1.198 (0.340)	1.999 (0.237)	–	0.017
Month end	−1.804 (0.354)	2.068 (0.239)	–	0.018
Before quarter end	−1.242 (0.810)	3.276 (0.624)	–	0.015
Quarter end	−7.243 (2.384)	14.648 (2.773)	–	0.301
After quarter end	5.699 (1.987)	10.448 (3.250)	–	0.153
Before year end	−3.531 (2.206)	6.472 (1.835)	–	0.016
Year end	−4.363 (2.945)	6.917 (4.321)	–	0.019
After year end	3.378 (3.274)	20.661 (8.702)	–	0.168
All jumps				0.833
Long run mean spreads			−6.108 (0.547)	
95% confidence interval:			[−7.02, −5.23]	
99% confidence interval:			[−7.43, −4.85]	

The table reports results of MCMC estimation of the model. Standard errors are reported in parentheses, and are computed from the estimated posterior distribution of the coefficients. The sample includes 1,562 daily observations from October 13, 1999, to January 25, 2006.

Table 5
Agency–MBS Spread Estimation

Diffusion coefficients			Estimates	
α_S			−0.336 (0.019)	
β_S			−0.419 (0.020)	
α_V			0.008 (0.002)	
β_V			0.961 (0.010)	
σ			0.090 (0.009)	
ρ			−0.096 (0.050)	
Jump coefficients	**Mean jump**	**Variance of jump**	**Arrival Intensity**	**Share of estimated variance**
Random jump	−3.575 (1.954)	3.337 (0.792)	0.004 (0.002)	0.039
Before holiday	0.041 (0.106)	0.636 (0.071)	–	0.016
After holiday	−0.135 (0.103)	0.606 (0.067)	–	0.015
15th	−0.160 (0.085)	0.570 (0.059)	–	0.015
First day of month	0.138 (0.106)	0.607 (0.069)	–	0.017
Month end	−0.215 (0.112)	0.641 (0.076)	–	0.019
Before quarter end	−0.048 (0.235)	0.857 (0.145)	–	0.011
Quarter end	−1.365 (0.590)	2.354 (0.442)	–	0.087
After quarter end	0.456 (0.377)	1.303 (0.255)	–	0.027
Before year end	−1.312 (0.671)	1.341 (0.355)	–	0.008
Year end	−2.165 (2.441)	9.533 (2.300)	–	0.398
After year end	2.322 (1.867)	5.746 (1.420)	–	0.145
All jumps				0.796
Long run mean spreads			−0.915 (0.052)	
95% confidence interval:			[−1.00, −0.83]	
99% confidence interval:			[−1.04, −0.80]	

The table reports results of MCMC estimation of the model. Standard errors are reported in parentheses, and are computed from the estimated posterior distribution of the coefficients. The sample includes 1,562 daily observations from October 13, 1999, to January 25, 2006.

First, all spreads exhibit a clear pattern with negative deterministic jumps at month-ends, quarter-ends, and year-ends, followed by (partially) offsetting jumps in the immediately following days. The negative jumps are especially large for the $S_t^{TRE-AGE}$ and $S_t^{TRE-MBS}$ spreads and cumulate across different calendar events to deliver mean total jumps of −13.5 basis points at year-ends and −9 basis points at quarter-ends, for both the $S_t^{TRE-AGE}$ and $S_t^{TRE-MBS}$ spreads. About three-quarters of these negative jumps are offset, on average, by positive jumps on the immediately following days, with the residual dissipating slowly over time as an effect of mean reversion. Mean jumps occurring around holidays and mid-months are estimated to be smaller, at less than 1 basis point. Our results point to very rich seasonal patterns in money market spreads. The estimation process allows us to determine the significance of seasonal factors and observe the magnitude and dynamics associated with these important calendar events.

Second, random jumps are also sizable, with mean estimated sizes of −4.4, −5.5, and −3.6 basis points, respectively, for the three $S_t^{TRE-AGE}$, $S_t^{TRE-MBS}$, and $S_t^{AGE-MBS}$ spreads. Yet, the low estimated intensities for these processes (about 1% per day for the $S_t^{TRE-AGE}$ and $S_t^{TRE-MBS}$ spreads, and 0.4 % per day for the $S_t^{AGE-MBS}$ spread) imply that random jumps make only a small contribution to explaining the total variance of the spread processes: The share of the estimated variance of the spread attributed to random jumps ranges between 4% and 9% across the three spreads, as shown in the rightmost columns (mid-panel) in Tables 3–5. This small contribution is especially surprising when considering that random jumps can occur every day other than days assigned to deterministic jumps. By contrast, the deterministic jumps explain about 75% of the estimated variance of all spreads, with jumps occurring around ends of months/quarters/years alone accounting for over 70% of the estimated variances. Thus, flight-to-quality effects at predictable calendar times are apparent and are estimated to dominate the dynamics of our collateral spreads. The term "flight-to-quality" refers to two distinct classes of events in our article. First, it refers to panics in the market that cause investors to rush into Treasury securities over (and to some degree from) other securities considered in this article. Second, it refers to the demands that arise in quarter-ends and year-ends in order for institutions to achieve certain balance-sheet outcomes for reporting purposes. Both classes of events refer to situations where institutions prefer to hold higher-quality and more-liquid instruments. A finding of our article is that both types of events are of economic interest, in general. Their relative importance may vary with the state of the financial markets. For example, our sample period did not cover the credit crisis period during which the random jumps in the GC repo spreads might have dominated. Indeed, we have alluded in the introduction to some evidence that suggests that this was the case.

We can summarize much of the insight from our estimation by presenting estimated unconditional (long-run) means of the spread processes, which are displayed in the lower panels of Tables 3–5 with their standard errors.[18] The estimated unconditional means confirm that our three classes of collateral follow a clear pecking order: Repo financing against Treasury securities is available at 5.2 basis points less than against agency securities and at 6.1 less than against MBSs. (The numerically computed confidence intervals displayed in the table show that these spreads are statistically significant at any standard confidence level.)

3.4.2 Collateral rents. What determines the value of the collateral spreads between Treasury and agency/mortgage-backed securities? To address this question with regard to both dynamics and long-run trends, we use the unsecured rates to investigate the empirical behavior of the collateral rents S_t^{FF-TRE}, S_t^{FF-AGE}, and S_t^{FF-MBS}, following the same methodology we used to study collateral spreads in the previous section.

Results of our estimation are presented in Tables 6–8. The estimation has two highlights: explaining the time variation in the collateral spreads through

18 Since the spread processes modeled by Equation (7) are affine, the unconditional means are easy to compute analytically; however, their standard errors must be obtained numerically, as part of the MCMC simulations.

Table 6
Federal Funds 9 a.m. Rate—Treasury Spread Estimation

Diffusion coefficients	Estimates
α_S	0.730 (0.134)
β_S	−0.179 (0.024)
α_V	0.320 (0.172)
β_V	0.995 (0.002)
σ	0.119 (0.048)
ρ	0.047 (0.096)

Jump coefficients	Mean jump	Variance of jump	Arrival Intensity	Share of estimated variance
Random jump	5.801 (10.397)	22.627 (7.558)	0.002 (0.002)	0.013
Before holiday	−0.148 (1.113)	4.452 (0.689)	–	0.009
After holiday	1.008 (1.111)	4.448 (0.670)	–	0.009
15th	1.275 (0.962)	4.134 (0.576)	–	0.009
First day of month	−1.158 (1.119)	4.394 (0.673)	–	0.010
Month end	2.769 (1.156)	4.653 (0.726)	–	0.011
Before quarter end	1.232 (1.797)	6.091 (1.340)	–	0.006
Quarter end	5.791 (2.259)	8.624 (2.282)	–	0.013
After quarter end	−3.089 (2.154)	7.500 (1.800)	–	0.010
Before year end	2.214 (2.953)	16.293 (5.062)	–	0.013
Year end	1.109 (3.151)	47.328 (11.309)	–	0.110
After year end	−0.990 (3.159)	54.257 (12.649)	–	0.144
All jumps				0.358

Long run mean spreads	5.569 (0.539)
95% confidence interval:	[4.67, 6.44]
99% confidence interval:	[4.27, 6.82]

The table reports results of MCMC estimation of the model. Standard errors are reported in parentheses, and are computed from the estimated posterior distribution of the coefficients. The sample includes 1,562 daily observations from October 13, 1999, to January 25, 2006.

Table 7
Federal Funds 9 a.m. Rate—Agency Spread Estimation

Diffusion coefficients	Estimates
α_S	0.197 (0.103)
β_S	−0.419 (0.026)
α_V	0.171 (0.189)
β_V	0.993 (0.004)
σ	0.137 (0.035)
ρ	0.056 (0.078)

Jump coefficients	Mean jump	Variance of jump	Arrival Intensity	Share of estimated variance
Random jump	8.837 (7.423)	15.529 (4.752)	0.006 (0.004)	0.031
Before holiday	−0.259 (0.708)	3.194 (0.511)	–	0.009
After holiday	0.960 (0.702)	3.134 (0.496)	–	0.009
15th	0.487 (0.609)	2.939 (0.438)	–	0.009
First day of month	0.210 (0.725)	3.133 (0.479)	–	0.011
Month end	0.616 (0.751)	3.331 (0.489)	–	0.012
Before quarter end	0.186 (1.255)	4.134 (0.872)	–	0.006
Quarter end	1.346 (1.590)	4.778 (0.968)	–	0.008
After quarter end	0.413 (1.638)	5.234 (1.638)	–	0.010
Before year end	1.900 (2.824)	14.235 (3.969)	–	0.021
Year end	0.567 (3.117)	47.833 (10.638)	–	0.234
After year end	−0.934 (3.041)	29.552 (7.224)	–	0.089
All jumps				0.451

Long run mean spreads	0.918 (0.218)
95% confidence interval:	[0.58, 1.28]
99% confidence interval:	[0.45, 1.43]

The table reports results of MCMC estimation of the model. Standard errors are reported in parentheses, and are computed from the estimated posterior distribution of the coefficients. The sample includes 1,562 daily observations from October 13, 1999, to January 25, 2006.

Table 8
Federal Funds 9 a.m. Rate—MBS Spread Estimation

Diffusion coefficients			Estimates	
α_S			−0.234 (0.114)	
β_S			−0.452 (0.021)	
α_V			0.105 (0.159)	
β_V			0.991 (0.005)	
σ			0.190 (0.062)	
ρ			0.085 (0.064)	
Jump coefficients	Mean jump	Variance of jump	Arrival Intensity	Share of estimated variance
Random jump	11.131 (5.620)	13.441 (3.028)	0.005 (0.003)	0.038
Before holiday	−0.238 (0.546)	2.740 (0.385)	–	0.012
After holiday	0.916 (0.540)	2.621 (0.379)	–	0.011
15th	0.329 (0.451)	2.464 (0.315)	–	0.011
First day of month	0.393 (0.561)	2.699 (0.371)	–	0.014
Month end	0.301 (0.602)	2.918 (0.422)	–	0.016
Before quarter end	0.077 (1.011)	3.483 (0.685)	–	0.008
Quarter end	0.308 (1.415)	4.522 (0.934)	–	0.013
After quarter end	0.876 (1.440)	4.873 (1.166)	–	0.015
Before year end	1.792 (2.786)	14.084 (3.528)	–	0.035
Year end	0.607 (3.085)	38.590 (8.632)	–	0.266
After year end	−1.049 (2.987)	21.778 (5.512)	–	0.085
All jumps				0.525
Long run mean spreads			−0.162 (0.262)	
95% confidence interval:			[−0.50, 0.36]	
99% confidence interval:			[−0.59, 0.52]	

The table reports results of MCMC estimation of the model. Standard errors are reported in parentheses, and are computed from the estimated posterior distribution of the coefficients. The sample includes 1,562 daily observations from October 13, 1999, to January 25, 2006.

the jump behavior of the time series and the long-run determination of the collateral spreads through the unconditional means. First, consider the estimated deterministic jumps for the three series S_t^{FF-TRE}, S_t^{FF-AGE}, and S_t^{FF-MBS}, which we have seen play a critical role in the volatility of the collateral spreads. While deterministic jumps in the S_t^{FF-TRE} spread are large and comparable in magnitude to those estimated for the $S_t^{TRE-AGE}$ and $S_t^{TRE-MBS}$ spreads, the deterministic jumps for the S_t^{FF-AGE} and S_t^{FF-MBS} spreads are generally small. For instance, the cumulative mean of end-month, end-quarter, and end-year jumps in the S_t^{FF-TRE} spread is 9.7 basis points, while it is only 2.5 basis points for the S_t^{FF-AGE} spreads, indicating that agency-backed borrowing rates follow the unsecured rate much more closely.

The small S_t^{FF-AGE} jumps suggest that the $S_t^{TRE-AGE}$ spread is economically driven by changes in the collateral value of Treasury bonds. To disentangle whether the higher financing spreads observed around end-months, end-quarters, and end-years are driven by an increase in the value of Treasury as collateral, due to flight-to-quality effects, or a decrease in the value of agency or mortgage-backed securities as collateral, due to a perceived increase in risk or decrease in liquidity, we examine the borrowing-rate levels around these dates. An analysis of the first difference of the r_t^{TRE}, r_t^{AGE}, and r_t^{FF} on quarter-ends reveals that on all year-ends, and on many other quarter-ends, it is indeed a positve jump in the value of Treasury as collateral that drives the spread. On these days, r_t^{TRE} is dropping significantly and r_t^{AGE} is either dropping by much less or is rising slightly, the market clearly showing a preference for safe collateral as lenders forgo higher returns from lower-quality collateral. There are some quarter-ends where agency financing rates spike higher than Treasury rates. On these days, when the agency financing rate drives the $S_t^{TRE-AGE}$ spread, the fed funds unsecured rate also firms accordingly, indicating an overall tightness in the market as opposed to an increase in agency-specific risk. Thus, even when the agency rate is the mover of the $S_t^{TRE-AGE}$ spread, it reflects the premium that lenders are willing to surrender to obtain safe collateral on these tight days.

Second, and most importantly, the estimated unconditional means of the unsecured-secured spreads clearly indicates that the difference in collateral spreads between Treasuries and other securities can be attributed almost entirely to the value attached to Treasuries as collateral: The unconditional mean of the S_t^{FF-TRE} spread, at 5.6 basis points, fully explains the financing advantage to borrowers posting Treasuries as collateral relative to borrowers posting agency securities as collateral (an advantage we estimated at 5.2 basis points). Indeed, posting agency securities as collateral allows borrowers to save a mere 0.9 basis point relative to the cost of unsecured borrowing. The case of MBSs is even more extreme: Posting MBSs as collateral allows borrowers *no* saving relative to the cost of unsecured borrowing (the saving is technically negative, but minuscule and statistically insignificant). Our interpretation of this critical finding is that rather than gaining a meaningful price advantage when posting agency and mortgage-backed securities as collateral (relative to borrowing unsecured), owners of these securities can obtain (or expand) access to the funding market that they would not have otherwise.

Pertinent to our analysis are two additional factors on which data are difficult to obtain: transactions costs associated with repo transactions and the haircuts that are applied to different classes of collateral. However, we note that these factors are unlikely to trump the main results of our article for the following reasons. First, increased transactions costs in agency and mortgage-backed securities markets will only make our results stronger, as we have already demonstrated that these securities have negligible collateral rents. Second, absent times of crisis, haircuts appear to have a low elasticity to market conditions and change only sporadically. Excessive haircuts and higher transactions costs may further dampen the collateral rents of agency and mortgage-backed securities. In effect, we believe that these factors will cause Treasury, as a class, to be more preferred.

3.4.3 Volume analysis. In this section, we provide some evidence on the link between repo volumes and repo rates. In order to perform this analysis, we obtained data on volume from two sources. The first source of data is the daily primary dealer survey data. The second source is the weekly repo volume data maintained by the Federal Reserve.

The dealer survey data provide both the estimates of the dealers about how much they intend to finance that day using each type of collateral and the actual amount that they have financed at the time of the survey (usually a large percentage of total financing for the day). Clearly, the advantage of the dealer survey data is that they are of daily frequency, but the potential disadvantage is that they are based on a survey.

When using survey data, we aggregated across dealers for each day to get a daily series of repo financing volume by collateral type. When using the market data, we averaged the spreads on a weekly basis. Finally, we constructed the Treasury component of total volume as the (Treasury repo volume/total volume).

We performed the following regressions: regression of the Treasury component on the daily spread between Treasury and agency repo rates. We ran this regression with the data on the amount financed from the primary dealer survey and the market data. We present in Table 9 the summary of our results. To check the robustness of our findings, we also conducted a regression of the Treasury component on the spread between effective fed funds rates and the Treasury GC repo rates. The results were qualitatively similar. We also ran the regressions on a daily volume series produced using survey data on total expected amount to finance, instead of amount financed at time of survey. Once again, the results were qualitatively very similar.

Our results can be summarized as follows: First, the collateral spread enters as a statistically significant variable in volume regressions. Second, effects always go in the "right" direction: An increase in the Treasury-agency spread (which is negative) means that the Treasury repo rates are differentially going up (i.e., Treasury premium is lower), which is associated with a lower composition of Treasuries in repo financing. Depending on the data source,

Table 9
Treasury Composition Volume Regressions

	Survey Data	Market Data
Tres-Age Spread	−0.222	−0.334
	(0.034)	(0.043)
Constant	42.690	77.648
	(0.261)	(0.266)
# of observations	1565	232
R^2	0.027	0.206

The table reports ordinary least squares regressions of the Treasury component of total repo volume. Survey data are daily time series from the Federal Reserve Bank of New York's survey of primary dealers. Market data is cumulated weekly repo data maintained by the Federal Reserve. The independent variable is the Treasury-agency repo rate spread. Standard errors are reported in parentheses, with *** indicating lack of significance at the 10% level, ** indicating significance at the 10% level, * indicating significance at the 5% level, and no mark indicating significance at the 1% level.

a one basis point increase in the Treasury-agency spread is associated with a 0.22% or 0.33% decrease in the composition of Treasuries in repo financing. Finally, an analysis focusing around quarter-end dates finds Treasury composition almost universally moving in the predicted directions.

4. Impact of Collateral Values on Asset Prices

4.1 Pricing relationship

In this section, we provide a preliminary investigation of the impact of collateral values on the prices of assets. To this end, we first develop an asset-pricing relationship between repo spreads and yield spreads based on no-arbitrage arguments, and then explore the empirical relevance of that relationship using data from the Treasury and agency markets.

In the appendix to our article, we develop a pricing relationship that connects the GC repo spreads to the valuation differences between two asset classes. Our analysis leads to the following, potentially testable, empirical specification. Our analysis and the result below follow from Duffie (1996):

$$[A - T] = \frac{\sum_{i=t}^{N} z_{t,i} E\left(R_{iA} - R_{iT}\right)}{\sum_{i=t}^{N} z_i} + \frac{\sum_{i=t}^{N} cov\left(\lambda_{t,i}, R_{iA} - R_{iT}\right)}{\sum_{i=t}^{N} z_i}. \quad (9)$$

We can interpret Equation (9) as follows: The spread between agency and Treasury yields (at-issue par yields, to be precise) consists of two parts. The first part is the discounted expected stream of financing rate spreads. The second term is the covariance of the pricing kernel with the repo spreads. We may expect this covariance to be positive—as the Treasury repo rates drop due to a flight to quality, the repo spreads will increase. During this time, the pricing kernel, which is the marginal rate of substitution between current and future consumption, should also increase.

In this article, we focus on the first term on the right-hand side of our valuation equation and simply use standard empirical proxies for the latter term. Exploring the precise contribution of risk to the determination of spreads between yields on different classes of securities is clearly an important issue, which, however, deserves to be addressed independently. Our goal here is to estimate the term $\sum_{i=t}^{N} z_{t,i} E\left(R_{iA} - R_{iT}\right) / \sum_{i=t}^{N} z_i$ consistently with the empirical specification of Section 3 and then provide a first assessment of the contribution of this term to the variability of $[A - T]$.

4.2 Empirical evidence

We now investigate the empirical relevance of the pricing relationship developed above by linking the expected discounted stream of collateral spreads $\sum_{i=t}^{N} z_{t,i} E\left(R_{iA} - R_{iT}\right) / \sum_{i=t}^{N} z_i$ to the yield spread $[A - T]$. Data limitations suggest that we view the analysis in this section as preliminary. Most of the data ingredients for our analysis, including the constant maturity spreads

$A - T$, the zero-coupon discount factors z_i, and, naturally, the expected collateral spreads $E\left(R_{iA} - R_{iT}\right)$, are constructed under specific empirical assumptions. Despite these limitations, we are encouraged by the finding that collateral spreads contribute a significant fraction of the variability of short-term (three- and six-month) pricing spreads. By contrast, we find that the contribution of collateral spreads to the variability of pricing spreads at one-year and longer horizons is small.

The key step needed to estimate the empirical equivalent of Equation (9) is the calculation of $E\left(R_{iA} - R_{iT}\right)$ for all $i = t, \ldots, N$ and all t. To this end, for each t (that is, for each observation in our sample), we used the stochastic process estimated in Section 3 and simulated it forward by Monte Carlo, starting from the initial value $R_{tA} - R_{tT}$ for each t and computing the sample mean across paths for each i. All the sample means are then discounted to the present using the zero-coupon discounts z_i and summed up. For further reference, we denote the estimated first term of Equation (9) as x_t.

As for the other terms in the regression of Equation (9), the discount factors themselves are the Nelson-Siegel-Svensson discount rates estimated by the Board of Governors of the Federal Reserve; the dependent variable $A-T$ is the spread between the constant-maturity agency rate (provided by Fannie Mae) and the constant-maturity Treasury rate (provided by the Board of Governors of the Federal Reserve); and the empirical proxies for the risk term $\frac{\sum_{i=t}^{N} cov\left(\lambda_{t,i}, R_{iA}-R_{iT}\right)}{\sum_{i=t}^{N} z_i}$ are the conditional realized volatility, as a risk proxy, and the average daily bid-ask spreads between 8:00 and 9:00 a.m. for the on-the-run two-year note, which we use as a proxy for the liquidity premium. We denote the risk proxy as RP_t and the liquidity factor as L_t.

The arbitrage arguments are derived assuming that we are long in agency and short in Treasury so that $A - T$ always stays positive. In the empirical work, we have used the spreads $T - A$, but the resulting signs are consistent with the predictions of the theory. The regression equation that we estimate is specified below, with x_t simulated with respect to the $T - A$ spread:

$$[T_t - A_t] = a_0 + a_1 x_t + a_2 RP_t + a_3 L_t + \epsilon_t. \tag{10}$$

The constant term a_0 captures the non-time-varying spreads between Treasury and agency securities that we do not explicitly model. They may include possible tax effects: Treasury securities are tax exempt at state and city levels, whereas agency securities are taxable at all levels. The error term ϵ_t is assumed to be white noise. We estimate this equation for fixed maturity dates, and the results of regressions of Equation (10) are reported in Table 10 for six different terms: three and six months, and one, two, five, and ten years. We report results for two different sample lengths, with the length of the shorter sample determined by the availability of bid-ask spread data from BrokerTec.

Table 10
Pricing Spreads Regressions

	3 month spread					6 month spread				
	Full sample		Jan. 1, 2001 – Feb. 3, 2006			Full sample		Jan. 1, 2001 – Feb. 3, 2006		
Collateral	20.08	9.97	11.60	11.54	5.91	20.18	12.16	11.15	11.05	8.15
value	(1.06)	(0.88)	(0.76)	(0.77)	(0.66)	(1.46)	(1.27)	(1.00)	(1.01)	(0.95)
Conditional		−2.57			−2.15		−2.78			−1.44
volatility		(0.08)			(0.09)		(0.11)			(0.11)
Tres. bid-ask				−0.16***	0.14***				−0.19***	−0.02***
spread				(0.21)	(0.18)				(0.17)	(0.15)
Constant	84.83	44.16	45.52	45.17	24.15	88.57	57.56	45.92	45.39	35.21
	(5.60)	(4.52)	(4.00)	(4.02)	(3.37)	(7.63)	(6.57)	(5.24)	(5.26)	(4.90)
# observations	1548	1526	1243	1243	1221	1548	1526	1243	1243	1221
R^2	0.188	0.520	0.157	0.158	0.447	0.111	0.374	0.091	0.092	0.220

	1 year spread					2 year spread				
	Full sample		Jan. 1, 2001 – Feb. 3, 2006			Full sample		Jan. 1, 2001 – Feb. 3, 2006		
Collateral	46.04*	40.79	28.76	28.25	28.82	33.15	34.42	21.01	19.23	20.14
value	(3.89)	(3.76)	(2.89)	(2.90)	(2.84)	(4.91)	(4.89)	(3.71)	(3.70)	(3.45)
Conditional		−2.27			−0.51*		−0.13*			−1.75
volatility		(0.19)			(0.16)		(0.06)			(0.20)
Tres. bid-ask				−0.46**	−0.26***				−0.85	−0.66
spread				(0.25)	(0.25)				(0.18)	(0.17)
Constant	218.24	201.77	133.82	131.22	136.75	146.17	153.50	86.52	77.29	86.54
	(20.31)	(19.55)	(15.06)	(15.11)	(14.76)	(25.60)	(25.48)	(19.33)	(19.25)	(17.95)
# observations	1548	1526	1243	1243	1221	1546	1524	1243	1243	1221
R^2	0.083	0.165	0.074	0.076	0.092	0.029	0.035	0.025	0.043	0.105

	5 year spread					10 year spread				
	Full sample		Jan. 1, 2001 – Feb. 3, 2006			Full sample		Jan. 1, 2001 – Feb. 3, 2006		
Collateral	78.06	79.16	15.00***	10.76***	15.78***	80.63	69.32*	−26.19***	−31.24***	−38.73***
value	(13.73)	(13.54)	(10.37)	(10.23)	(9.49)	(27.84)	(27.16)	(20.74)	(20.59)	(19.58)
Conditional		−0.47			−1.48		−1.28			−2.44
volatility		(0.08)			(0.17)		(0.12)			(0.22)
Tres. bid-ask				−1.46	−1.17				−1.43	−1.25
spread				(0.23)	(0.22)				(0.30)	(0.29)
Constant	361.48	369.26	38.64***	16.72***	47.37***	358.82*	304.80*	−189.77**	−215.89*	−247.98***
	(71.47)	(70.48)	(53.94)	(53.24)	(49.39)	(144.84)	(141.27)	(107.86)	(107.07)	(101.84)
# observations	1546	1524	1243	1243	1221	1546	1524	1243	1243	1221
R^2	0.021	0.042	0.002	0.033	0.088	0.005	0.073	0.001	0.019	0.011

The table reports ordinary least squares regressions of constant maturity spreads between yields on Treasury and agency securities, for each term indicated in the table. The independent variables are the discounted stream of collateral values constructed as described in the text and normalized by the sum of the zero-coupon-based discount rates; the one-month moving average of conditional volatility, which is used as a proxy for risk conditions; and the average (linearly detrended) daily bid-ask spreads between 8:00 and 9:00 a.m. for the on-the-run two-year note, which is used as a proxy for liquidity conditions. Standard errors are reported in parentheses, with *** indicating lack of significance at the 10% level, ** indicating significance at the 10% level, * indicating significance at the 5% level, and no mark indicating significance at the 1% level.

The main lesson revealed from our regressions is that collateral values have significant explanatory power for the short-term Treasury-agency spread. The coefficients for the discounted streams of collateral values are highly significant for almost all specifications (their absolute values depend on the time units) and enter with the expected positive sign. Since both the collateral spreads and yield spreads are negative in sign, an increase in the variables represents a decrease in the spreads; thus, a decrease in collateral spreads is associated with a decrease in yield spreads. However, a more useful metric of this contribution is the fraction of explained variance of the left-hand-side variable, which is 19%, 11%, and 8%, respectively, at the three-, six-, and twelve-month maturities. The fraction of explained variance falls sharply beyond the one-year maturity, confirming previous evidence of sharp structural differences between money markets and longer-term markets.

As shown in Table 10, the realized conditional volatility as a proxy measure for risk in the regression is highly significant in all specifications and helps explain a good portion of the variance.[19] Additionally, the risk proxy enters with the anticipated negative sign (a higher realized conditional volatility, indicating a period of heightened risk, is associated with flight-to-quality effects and thus an increase in the spread $T - A$). In effect, the significance of the risk proxy in our regressions is suggestive that we have used an effective proxy for the risk term in our regression of cross-security bond yield spreads. While the inclusion of the risk proxy does somewhat reduce the magnitude of the estimated coefficients for the collateral values, the main results are qualitatively unchanged. The coefficients for the collateral values remain positive and highly statistically significant, and our simple model can explain 52%, 37%, and 17% of the variance of the dependent variable for the three-, six-, and twelve-month terms, respectively.

Finally, we included in our regressions measures of liquidity conditions, namely, average bid-ask spreads for the two-year on-the-run Treasuries between 8:00 and 9:00 a.m. (the same time interval over which our repo rates are sampled). Results of these regressions are also reported in Table 10.[20] We found our measures of liquidity to enter in the regressions with the anticipated negative sign (a larger spread, indicating tighter liquidity conditions, is associated with flight-to-quality effects, hence an increase in the spread $T - A$), although it is mostly statistically insignificant. Ultimately, the contribution of our liquidity proxy to explaining the variability of the pricing spreads is very small, leaving the estimated coefficients for the collateral values essentially unchanged.

Overall, our analysis in this section suggests that in conjunction with standard measures of risk and liquidity, collateral values can help explain a significant fraction of the variability of pricing spreads. It is encouraging that collateral values explain up to a fifth of the variability of these spreads for short-term instruments, suggesting this as a promising avenue for further investigation.

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19 The results of the regressions are robust to using other constructed measures of conditional volatility to proxy for risk. See Andersen, Bollerslev, Diebold, and Labys (2003) for a formal treatment of realized volatility.

20 The table reports results of regressions in which bid-ask spreads are linearly detrended, to account for the clear downward trend in both level and volatility of the bid-ask spreads during the sample, which clearly reflects the increased volume of trade on BrokerTec during the period. However, results using undetrended series were qualitatively similar.

5. Concluding Remarks

In this article, we have used a novel set of data on early morning repurchase agreements by primary securities dealers to document a number of features on the longitudinal and cross-security-class behavior of financing rates against GC.

One of our contributions is to substantiate the widely held—yet undocumented—view that three main classes of securities (Treasury securities, securities issued by government-sponsored agencies, and mortgage-backed securities) can be ranked in terms of their respective collateral values in the GC market: Holders of Treasury securities enjoy a considerable advantage in that they can borrow at considerably favorable rates relative to holders of securities issued by government-sponsored agencies and mortgage-backed securities. This advantage (which we quantify as an average unconditional spread of 5–6 basis points) displays significant temporal variation, and is especially large at times of predictable liquidity needs (such as quarter-ends and other special days). At these times, Treasury collateral values rise sharply, consistent with safe-haven effects in favor of Treasury securities.

Our analysis also allows us to measure the collateral rents earned by securities' owners as the spread between unsecured and secured loans and to document features of the time variation of these rents. We document the surprising fact that rates on repos using agency and mortgage-backed securities as collateral are not meaningfully different from unsecured rates, suggesting that posting of agency and mortgage-backed securities essentially enables owners of these securities to obtain (or expand) access to the funding market, although it does not generate any significant price advantage.

Finally, we link collateral values to asset prices in a simple no-arbitrage framework, showing that variations in collateral values should explain a significant fraction of changes in the prices of the underlying securities. We verify empirically that this conjecture holds true for pricing of short-term (money market) securities but not for the pricing of medium-term and long-term securities.

Appendix

To develop the needed pricing relationship, we make the following simplifying assumptions. First, we assume that Treasury and agency par bonds are issued in frictionless markets at the same time. We also assume all coupon payment dates to be the same for both types of security, and ignore any spread difference between repo and reverse repo agreements. Finally, we assume the cash flows for both types of securities to be free of default risk.

These assumptions may appear to be rather strong, but they allow us to derive a tractable theoretical link between the yield spreads of agency and Treasury securities, and their financing spreads. In addition, we are able to use the derived theoretical link to obtain empirically testable implications.

With these assumptions in place, we consider the following portfolio strategy. Sell an agency par bond with a coupon of A and go long in a Treasury par bond with a coupon of T. Both the long position in the Treasury security and the short position in the agency security are implemented using GC repo agreements that are renewed every day: The long Treasury position is financed by paying the repo rate in the GC repo market for Treasury, while the proceeds associated with the short sale of the agency security earn the repo rate in the GC repo market for agency debt. Note that on each date, the portfolio earns (on an accrual basis) the amount $A - T$, which is the difference between the agency coupon rate and the Treasury coupon rate. (In practice, we expect $A - T > 0$ to compensate for the fact that the Treasury security has a "safe haven" premium built into it, but this inequality is not needed for our pricing relationship.) Let this position be carried until maturity, at which point it is unwound.

The above-described position leads to the following valuation equation:

$$[A - T] \sum_{i=t}^{N} z_i = PV \left[\sum_{i=t}^{N} (R_{iA} - R_{iT}) \right], \tag{11}$$

where the z_i are the zero-coupon discount factors and R_{iA} and R_{iT} are the overnight repo rates against agency and Treasury collateral, respectively.

Note that since we assumed the securities to have been issued at par, then A and T can be interpreted as the respective coupons and at-issue par yields. Equation (11) then states that the present value of par yield spreads is simply the present value of repo spreads. In Equation (11), the constant-maturity Treasury and agency yields can be interpreted as yields on "new issue" bonds.[21]

Note that the left-hand side of the pricing relation (11) is the discounted present value of the differential cash flow rights between Treasury and agency security. The right-hand side is the present value of the differential collateral rights. In equilibrium, in the absence of default, liquidity, and tax differences, they must be equal: In other words, differences in valuation arising from differential cash flow rights can be fully explained by the differences in collateral rights. In the real world, such differences may also be driven by liquidity differences.

The pricing relation (11) can then be applied over time by recognizing that it should apply to the par yield spreads on each date. Since par yields in the Treasury and agency securities are estimated every day, we can then apply our valuation equation on the par yield spreads in the market.

To this end, let us explore the right-hand side of the valuation equation in greater detail by rewriting (11) as

$$PV \left[\sum_{i=t}^{N} (R_{iA} - R_{iT}) \right] = E \left[\sum_{i=t}^{N} \lambda_{t,i} (R_{iA} - R_{iT}) \right], \tag{12}$$

where the time-varying pricing kernel $\lambda_{t,i}$ covaries with the repo spreads. We can then expand the pricing relationship and exploit the fact that

$$E \left[\lambda_{t,i} \right] = z_{t,i}, \tag{13}$$

[21] Several points are worthy of note. First, we assume that the agency debt securities are free of default risk. This may be called into question, as they are not backed by the full faith and credit of the United States government. At the time of writing this article, it was a widely held belief among the market participants that the Government Sponsored Enterprises would not be allowed to fail. In fact, in September 2008, the Treasury announced a conservatorship program and essentially took Fannie Mae and Freddie Mac under its wings. Second, the assumption that repo and reverse repo transactions are carried until maturity is a conceptual device, which allows us to get a tractable specification. Finally, it should be noted that in Equation (11), a long position is held in agencies and a short position in Treasuries. Short positions are established in "specials" markets, but for empirical implementation, we will be using the GC rates. This actually biases our model toward rejection, as special rates are much lower than GC rates, and financing spreads using the Treasury special rates are likely to exhibit greater co-movements with yield spreads.

which states that the expected value of the pricing kernel is the price of a zero-coupon bond at the time expectation is taken. Plugging this into the valuation equation and simplifying, we get

$$PV\left[\sum_{i=t}^{N}\left(R_{iA}-R_{iT}\right)\right]=\sum_{i=t}^{N}z_{t,i}\,E\left(R_{iA}-R_{iT}\right)+\sum_{i=t}^{N}cov\left(\lambda_{t,i},R_{iA}-R_{iT}\right)\ . \tag{14}$$

We can further simplify as follows:

$$[A-T]\sum_{i=t}^{N}z_i=\sum_{i=t}^{N}z_{t,i}\,E\left(R_{iA}-R_{iT}\right)+\sum_{i=t}^{N}cov\left(\lambda_{t,i},R_{iA}-R_{iT}\right)\ , \tag{15}$$

or, rearranging,

$$[A-T]=\frac{\sum_{i=t}^{N}z_{t,i}\,E\left(R_{iA}-R_{iT}\right)}{\sum_{i=t}^{N}z_i}+\frac{\sum_{i=t}^{N}cov\left(\lambda_{t,i},R_{iA}-R_{iT}\right)}{\sum_{i=t}^{N}z_i}\ . \tag{16}$$

References

Andersen, T., T. Bollerslev, F. Diebold, and P. Labys. 2003. Modeling and Forecasting Realized Volatility. *Econometrica* 71:579–625.

Bindseil, U., K. Nyborg, and I. Strebulaev. 2002. Bidding and Performance in Repo Auctions: Evidence from ECB Open Market Operations. ECD Working Paper 157.

———. 2009. Repo Auctions and the Market for Liquidity. *Journal of Money, Credit, and Banking* 41:1391–421.

Brunnermeir, M. K., and L. H. Pedersen. 2009. Market Liquidity and Funding Liquidity. *Review of Financial Studies* 22:2201–38.

Cornell, B., and A. C. Shapiro. 1989. The Mispricing of U.S. Treasury Bonds: A Case Study. *Review of Financial Studies* 2:297–310.

Duffie, D. 1996. Special Repo Rates. *Journal of Finance* 51:493–526.

Eraker, B., M. Johannes, and N. Polson. 2003. The Impact of Jumps in Volatility and Returns. *Journal of Finance* 58:1269–300.

Fleming, M., and K. Garbade. 2002. When the Back Office Moved to the Front Burner: Settlement Fails in the Treasury Market after 9/11. *Economic Policy Review* 8(2):35–57.

———. 2003. The Repurchase Agreement Refined: GCF Repo. *Current Issues in Economics and Finance* 9(2):1–7.

Garleanu, N., and L. H. Pedersen. 2009. Margin-based Asset Pricing and Deviations from the Law of One Price. Working Paper, New York University.

Geanakaplos, J. 1997. Promises, Promises. In W. B. Arthur, S. Durlauf, and D. Lane (eds.), *The Economy as an Evolving Complex System II*, pp. 285–320. Reading, MA: Addison-Wesley.

———. 2003. Liquidity, Default, and Crashes: Endogenous Contracts in General Equilibrium. In M. Dewatripont, L. P. Hansen, and S. J. Turnovsky (eds.), *Advances in Economics and Econometrics: Theory and Applications, Eighth World Conference*, Vol. 2, Ch. 5, pp. 170–205. Cambridge: Econometric Society Monographs.

———. 2009. The Leverage Cycle. Cowles Foundation Discussion Paper 1715.

Gurkaynak, R. S., B. Sack, and J. H. Wright. 2007. The U.S. Treasury Yield Curve: 1961 to the Present. *Journal of Monetary Economics* 54:2291–304.

Herring, R., and T. Schuermann. 2005. Capital Regulation for Position Risk in Banks, Securities Firms, and Insurance Companies. In H. S. Scott (ed.), *Capital Adequacy Beyond Basel: Banking, Securities, and Insurance*, Ch. 1, pp. 15–86. New York: Oxford University Press.

Heston, S. L. 1993. A Closed-form Solution for Options with Stochastic Volatility with Applications to Bond and Currency Options. *Review of Financial Studies* 6:327–43.

Jacquier, E., N. Polson, and P. Rossi. 1994. Bayesian Analysis of Stochastic Volatility Models. *Journal of Economics and Business Statistics* 12:371–89.

Johannes, M., and N. Polson. 2006. MCMC Methods for Continuous-time Financial Econometrics. In Y. Ait-Sahalia and L.-P. Hansen (eds.), *Handbook of Financial Econometrics*, Vol. 2, Ch. 13. Oxford: Elsevier.

Jordan, B. D., and S. D. Jordan. 1997. Special Repo Rates: An Empirical Analysis. *Journal of Finance* 52: 2051–72.

Krishnamurthy, A. 2002. The Bond/Old-bond Spread. *Journal of Financial Economics* 66:463–506.

Longstaff, F. A. 2004. The Flight-to-liquidity Premium in U.S. Treasury Bond Prices. *Journal of Business* 77:511–26.

Markets Group of the Federal Reserve Bank of New York. 2009. Domestic Open Market Operations During 2008. Technical Report.

Musto, D. K. 1997. Portfolio Disclosures and Year-end Price Shifts. *Journal of Finance* 52:1563–88.

Securities Industry and Financial Markets Association. 2009. Research Statistical Tables: "U.S. Bond Market Outstanding" and "U.S. Primary Dealer Financing". Technical Report.

Staff Publications Committee. 2009. Statistical Supplement to the Federal Reserve Bulletin. Technical Report, Board of Governors of the Federal Reserve Bank.

Sundaresan, S. 1994. An Empirical Analysis of U.S. Treasury Auctions: Implications for Auction and Term Structure Theories. *Journal of Fixed Income* 4(2):35–50.

Sundaresan, S., and Z. Wang. 2009. Y2K Options and Liquidity Premium in Treasury Markets. *Review of Financial Studies* 22:1021–56.

Treasury Market Practices Group. 2009. Treasury Market Best Practices. Technical Report.