

Public Provision of Private Liquidity

Prior to the Millennium Date Change

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Abstract

The Millennium Date Change (often referred to as Y2K) was anticipated to be a major aggregate liquidity event by many financial and corporate institutions as well as the central banks around the world. We document the actions taken by the central bank in the United States to deal with this potential aggregate liquidity event, and provide an estimate of the aggressiveness of the demand for public provision of private liquidity during this period. We then apply economic theory to interpret and understand the liquidity premium in government debt and the actions of the U.S. central bank in the period surrounding Y2K. In the presence of this potential aggregate liquidity shock, the cost of private loans and insurance increased significantly, but the liquidity premium on government debt securities did not increase. The Fed successfully provided liquidity insurance and reduced the liquidity premium on government debt securities prior to Y2K by taking various actions including by issuing Y2K options. These findings are consistent with the predictions of economic theory. Our analysis links the behavior of the liquidity premium in government debt securities to the public provision of private liquidity.

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Contents

1	Introduction	3
2	The Theory and Its Testable Implications	5
2.1	The Demand and Supply of Liquidity	5
2.2	Implications for Financial Markets	8
3	Private Sector Liquidity Prior to Y2K	11
3.1	Decrease of the Supply of Private Financial Claims	11
3.2	Increase of the Cost of Private Loans	13
3.3	Escalation of the Premium of Private Insurance	16
3.4	Behavior of the Liquidity Premium in Government Debt	17
4	Public Provision of Liquidity Prior to Y2K	20
4.1	Actions Taken by the U.S. Central Bank	20
4.2	The Demand and Supply of Y2K Options	24
4.3	Econometric Models for the Effects of Y2K Options	26
4.4	Empirical Tests of Y2K Options' Effects	30
5	Conclusion	33
6	References	36
7	Tables and Figures	38

1 Introduction

Liquidity or “ready access to funds” is paramount to the survival of firms and financial intermediaries¹. Liquidity is especially paramount when there is an aggregate liquidity shock (or aggregate uncertainty) that may lead to an overall shortage of liquidity in the economy. A lack of liquidity often leads corporate borrowers and financial institutions to default during the first few days or weeks following a major liquidity crisis. The Millennium Date Change (also referred to as either Y2K or Century Date Change) was viewed, ex-ante, as a potential period of aggregate liquidity shortage. The supply and demand of liquidity ahead of Y2K is the focus of our enquiry.

In this paper, we investigate the liquidity of financial markets around Y2K to answer the following questions: What happened to the supply and demand of liquidity around Y2K? What economic theory can we apply to understand the behavior of corporations and the actions of the central bank around Y2K? What actions did the central bank take during the liquidity crisis of Y2K? Are the central bank’s actions consistent with economic theory? What are the effects of the central bank’s actions? We especially try to understand how the supply of liquidity by the public sector affects the liquidity premium in government debt securities during the period surrounding Y2K.

We first observe that the potential liquidity crisis associated with the Millennium Date Change (MDC) represented a liquidity state with a foreseeable date, namely January 1, 2000. This is consistent with the assumption in the economic theory developed by Holmstrom and Tirole (1996, 1998, 2001) on public provision of liquidity in anticipation of potential aggregate liquidity shocks. We demonstrate that, consistent with the theory, the provision of liquidity by the private sector was prohibitively expensive during the Millennium Date Change. We examine the actions taken by the central bank in providing liquidity and the premium demanded by the private sector on government debt. Our examination sheds light

¹Through out this paper, we use liquidity to refer to access to funds or credit markets while economists often use the term “liquidity” to mean different but related things.

on the validity of economic theory on public provision of private liquidity. We point out that the central bank's creation of state-contingent policy measures, such as Y2K options, to deal with the potential aggregate liquidity shock is in conformity with the prediction of economic theory. We conduct econometric tests to show that the liquidity facilities set up by the Federal Reserve Bank in the U.S. in the second half of 1999 helped to reduce the liquidity premium demanded by the market on government debt securities in the period surrounding the Millennium Date Change.

Liquidity provision and the liquidity premium have been topics of long-standing research in economics and finance, which can be classified into two strands. The first strand of research focuses on the macroeconomics of the private and public provision of liquidity in periods of liquidity shortage. The role of commercial banks in private markets for provision of liquidity has been addressed by a number of papers including Diamond and Dybvig (1983) and Diamond (1997). The role of the central bank and the use of public (government) debt to provide liquidity has received considerable attention, dating back to the contribution of Diamond (1965) and continuing in the work of Woodford (1990), and Holmstrom and Tirole (1996, 1998, 2001).

The second strand of research focuses on the microstructure of the liquidity premium in new issues of government debt and the factors that contribute to this premium. Liquidity premium is usually measured by the spread between on-the-run and off-the-run Treasury bonds. This line of inquiry includes papers by Kamara (1994), Duffie (1996), Jordan and Jordan (1997), Krishnamurthy (2002), Fleming (2003), Goldreich, Hanke and Nath (2004), etc. These papers either describe the behavior of the spreads or attempt to explain the presence of the liquidity-related spreads using bid-offer spreads, repo rates, and market prices of government debt and other debt securities. In our study of the Y2K event, we relate the behavior of on/off-the-run spread (i.e., a measure of liquidity premium) to the public, as well as private, provision of liquidity. Our research therefore links the above two strands of research, which have evolved independently in the literature.

Our paper proceeds as follows. In Section 2, we trace out some of the broad empirical implications of the received theory on public provision of private liquidity. We focus on the implications of Woodford (1990) and Holmstrom and Tirole (1996, 1998, 2001). In Section 3, we show that although the private provision of liquidity was prohibitively expensive in the period surrounding the Millennium Date Change, the liquidity premium in government securities did not increase. In Section 4, we discuss the state-contingent provision of the liquidity by the central bank and evaluate its effects on the liquidity premium in government debt securities. In Section 5 we conclude and suggest directions for future work.

2 The Theory and Its Testable Implications

2.1 The Demand and Supply of Liquidity

In a series of papers, Woodford (1990) and Holmstrom and Tirole (1996, 1998, 2001) explore the public provision of private liquidity and the manner in which liquidity may be priced in financial assets and particularly in government debt securities. They provide a theoretical basis with which to link the presence or absence of the liquidity premium in government debt securities to the presence or absence of aggregate liquidity constraints and shocks in the economy. We now briefly describe the theory developed by Woodford (1990) and Holmstrom and Tirole (1996, 1998).

Woodford (1990) considers the role played by public debt in economies in which households may be liquidity-constrained. If the household is unable to borrow against its illiquid future income, then the presence of public debt allows the household to smooth intertemporal consumption in a manner that would not be possible otherwise. In this sense, the presence of public debt improves the efficiency of consumption and wealth allocations. Woodford (1990) argues that “a higher public debt, insofar as it implies higher proportion of liquid assets in private sector wealth, increases the flexibility of the private sector in responding to variations in both income and spending opportunities, and so can increase economic efficiency.”

In fact, Woodford (1990) argues that increased public debt may increase investment to the extent that it alleviates the liquidity constraints of investors who have access to productive opportunities. He also shows that public debt will command a liquidity premium in a liquidity-constrained economy. Woodford (1990) does not explicitly consider the presence of private sector instruments to alleviate liquidity constraints.

Holmstrom and Tirole (1996, 1998) argue that in the presence of aggregate uncertainty (or aggregate liquidity shocks) the private sector of an economy may not be able to satisfy its own liquidity needs. Under such a scenario, government can improve welfare by issuing risk-free debt securities that command a liquidity premium over securities issued by entities in the private sector. Their papers provide a rationale as to why government securities such as T-bills, T-notes and T-bonds may command a liquidity premium relative to the claims issued by private sector entities when there is aggregate uncertainty or liquidity constraints. In addition, they also argue for an active management of government debt issuance. *Ceteris paribus*, the government should issue more debt securities when anticipated aggregate liquidity shocks are high and vice versa. In a broader sense, they argue that the government (the central bank) should use state contingent bonds to alleviate aggregate liquidity shocks. In this context, discount window activities may be thought of as state contingent bonds because the Fed adjusts the borrowing rate in response to market conditions.

To demonstrate their points, Holmstrom and Tirole (1998) construct “an entrepreneurial model of moral hazard” in which the value of a firm is strictly more than the combined value of all the claims on it. Firms in their model make decisions to raise money on date 0 to fund a variable-sized project which pays off on date 2. The payoffs on date 2 depend on the effort expended by the entrepreneur. On date 1, firms may experience a liquidity shock which may lead the firms to make additional investments on date 1. In a dynamic context, such liquidity shocks can force a firm to terminate its project even though the project has a positive net present value. Therefore the credit-constrained firm will have to trade off high initial investment on date 0 with the risk that a liquidity shock on date 1 may terminate the

project prematurely. Holmstrom and Tirole (1998) show that it is optimal for a firm and its investors to limit the initial investment as well as the amount that the firm is allowed to spend on the liquidity shock. The solution then takes one of two forms: the firm gets all the necessary funds on date 0, but will sign a liquidity covenant whereby the firm will set aside some funds to meet the liquidity shock on date 1. Alternatively, the firm will get limited funds on date 0 but will sign a credit line with the investors.

Their model therefore creates a demand for liquidity insurance. Such insurance can take the form of government securities, private sector securities and loan commitments from banks and other financial institutions. The supply of liquidity is influenced by precisely the same agency problem that limits the amount of financing that private sector firms can raise ex-post. The private security markets are constrained because there is limited capacity for transferring liquidity from one period to the next. As Holmstrom and Tirole note, the interplay between the ex-post agency problem of the individual firm and the ex-ante commitment problem of the investor delivers the main implications of their theory. Their theory suggests that in the absence of aggregate liquidity shocks, financial intermediaries such as banks will be able to meet the liquidity needs of the market. But when there is an aggregate liquidity shock, only government securities can provide credible liquidity insurance. In such situations, the government securities will command a liquidity premium.

Based on their theory, Holmstrom and Tirole offer a clear recommendation on public policy. They propose that central banks issue state-contingent securities in anticipation of aggregate liquidity shocks. Holmstrom and Tirole (1996) argue: *“The natural remedy in our model is to issue state-contingent bonds that pay off only when the private sector experiences a shortage of liquidity.”* However, Holmstrom and Tirole (1998) point out that state-contingent bonds are not used in practice. They identify the reason for the absence of state-contingent bonds as the lack of measurable information about the timing of the aggregate liquidity shocks. They offer the following interpretation of their results: *“The most obvious reason why such bonds are not used is that there is no aggregate, measurable state that unequivocally*

identifies times when firms should be provided more liquidity. Rather than the use of bonds that are contingent on a few foreseeable and verifiable variables, a discretionary policy may be more effective (when commitment and credibility problems associated with such a policy are ignored). Thus we view the use of state-contingent bonds as a metaphor for active government policy rather than as a serious policy instrument in its own right.” In addition, Holmstrom and Tirole (1996) make the following specific point about discount window: *“the discount window can be interpreted as an insurance scheme against liquidity shocks.”*

2.2 Implications for Financial Markets

Applying and testing the theory of Woodford and Holmstrom and Tirole requires us to identify more precisely the meaning of aggregate uncertainty or liquidity constraints. In their model, Holmstrom and Tirole (1998) assume that the time at which the aggregate uncertainty occurs is known in advance. Many economic circumstances fit this assumption about the timing of liquidity shocks: year-ends and Christmas holidays are typically associated with uncertain liquidity demands for which the central bank must plan ahead. However, as we demonstrate later in the paper, the liquidity shocks in the previous year-end periods were much less severe than Y2K.

There is an important difference between liquidity events whose timing is known ahead and liquidity events whose timings were not foreseeable such as the Russian default or the collapse of Long-Term Capital Management in August 1998. Uncertainty of timing limits the strategies that are open to the central bank. The timing of Millennium Date Change, on the other hand, fits Holmstrom and Tirole’s (1998) assumption squarely. It represents an ideal setting to test the implications of the models of Woodford and Holmstrom and Tirole.

The Millennium Date Change was also widely viewed as a potential source of aggregate liquidity shock. In 1999, Alan Greenspan, the Chairman of the Federal Reserve, clearly illustrated the fear of the crisis perceived by influential market participants.² Other rep-

²See *Remarks by Chairman Alan Greenspan before the President’s Council on Year 2000 Conversion*,

representatives of the central bank saw elements of “panic” or “extreme risk aversion” in the market.³ The economic effects of adjusting to the Millennium Date Change were seen as a major challenge. This perception in addition to other market data, which we summarize later, led the central bank to conclude that the Millennium Date Change was likely to be an aggregate liquidity event and prompted it to take several state-contingent actions.

Although the strategies of central banks and the market liquidity premium in year-ends and holidays can also be tested using our approach, the Millennium Date Change, in our opinion, represents a potential liquidity crisis of far greater magnitude. More importantly, the actions taken by the central bank during the MDC allow us to estimate the aggressiveness of the demand for the public provision of private liquidity. This is an essential step in answering some of the issues raised in the paper. Hence, we will investigate the hypothesis that the period of the Millennium Date Change, ex-ante, was viewed by the market as a period of aggregate liquidity shock or liquidity constraints. We examine the issuance activities and market prices of private sector claims and government securities during this period, using as our frame of reference, the empirical implications of Holmstrom and Tirolo (1998).

Holmstrom and Tirolo’s (1998) model has several implications for the financial markets around Y2K. First, if no aggregate liquidity shocks are expected to occur at Y2K, their model predicts that private sector liquidity insurance will be sufficient and so there will be no need for the government to provide liquidity. Therefore, in periods when no aggregate uncertainty is anticipated, government debt securities should not carry any incremental liquidity premium exclusively on this account.

Second, in the presence of aggregate uncertainty or liquidity shocks related to Y2K, securities issued by private sector entities will be unattractive as a means to obtain liquidity insurance. There are two inter-related factors at work that make private sector securities unattractive. The counterparty default risk is a major inhibiting factor. This may cause

September 17, 1999, Washington D.C.

³See Peter Fisher: *Money Market and the Century Date Change*, Federal Reserve Bank of New York, December 1, 1999.

dealers and issuers of private claims to withdraw from the market during the Y2K period. This withdrawal in turn will reduce the market liquidity. In this case, the supply of government debt securities will fill the liquidity breach. If the supply of government securities is insufficient, they will command a liquidity premium as the private sector is willing to hold these low-yielding government debt securities for obtaining credible liquidity insurance from aggregate uncertainty. The withdrawal of dealers from the market may limit the ability of government to intervene and alleviate the liquidity crisis. Hence, the government will have an incentive to intervene before the dealers withdraw from the market.

Third, and perhaps the most important, Holmstrom and Tirole's (1998) model predicts that state-contingent measures by government to alleviate liquidity shortages are generally effective. We will show that this is exactly what happened prior to the Millennium Date Change. Through discount windows, the Federal Reserve Bank of New York offered a large quantity of free liquidity options that matured around the Millennium Date Change. In addition, through seven auctions, the Federal Reserve Bank of New York also sold a large amount of liquidity options to bond dealers. We will describe the state-contingent actions initiated by the Fed in response to the Y2K problem. We will examine the extent to which the state-contingent actions taken by the Fed influenced the liquidity premium in government debt securities. Our evidence shows that the response of the Fed was consistent with the policy prescriptions of economic theory and that the actions of the Fed served to reduce the liquidity premium in the second half of 1999, just prior to the Millennium Date Change.

In the next section, we will examine private sector security prices prior to the Millennium Date Change. We will show that the private sector insurance was indeed abnormally expensive relative to the government debt during the Millennium Date Change.

3 Private Sector Liquidity Prior to Y2K

3.1 Decrease of the Supply of Private Financial Claims

A major implication of Holmstrom and Tirole's (1998) theory is that in the presence of aggregate liquidity shock, private markets will be liquidity-constrained. The issuance of private claims during a period of aggregate liquidity shock should slow down as their effectiveness in providing liquidity insurance is poor. To check this implication, we examine the issuance of securities in 1999. We construct Table 1 from the Federal Reserve Flow of Funds data in the March 2000 Issue (Table F.4 — Credit Market Borrowing, by instrument). The flow data in the table represent the situation of credit market borrowing in all sectors. The data are annualized and seasonally adjusted. The amounts are in billions of U.S. dollars. The numbers in parentheses indicate the percentage share of each sector's supply. We only present the instruments that are most relevant to our study.

The supply of government securities during the last quarter of 1999 dominated the supply of all other private sector claims combined: it alone accounted for 77% of the net issuance. The Fed flow of funds account lists bank loans and corporate and foreign bonds separately. Since our focus is private versus public debt, we report in Table 1 the aggregate behavior of both bank loans and corporate and foreign bonds. First, note that corporate equity issuance actually declined over this quarter. The aggregate issuance of bank loans and Corporate and Foreign bonds also declined from \$826.7 billion (67% share) in the first quarter of 1999 to just over \$166 billion (24% share) by the fourth quarter of 1999⁴.

Two points are worthy of special note: first the overall net issuance fell from 1225.8 billion in the first quarter to 684 billion in the fourth quarter. This is a drop of 44% in issuance. Next, as a proportion of net new security issuance, government securities represented 77% in the fourth quarter of 1999, which is a sharp increase from a little over 42% in the first quarter

⁴The pattern for bank loans alone suggests that the share actually increased although the overall volume of loans showed a mixed pattern. This evidence is roughly consistent with the notion that banks provide liquidity better than corporate bond markets in periods of stress.

of 1999. In part, this drop may be ascribed to the increased spreads that we document in Figure 2.⁵ This change in the mix of issuance, as well as the change in overall volume, is broadly consistent with the implications of economic theory.

In fact, banks shifted settlements of forward transactions away from the Millennium Date Change. The withdrawal by a number of institutions during this period may have discouraged trading, issuance and investment during the Millennium Date transition. A signal for the shift of transactions away from the Millennium Date Change could be seen in June 1999 when the term spread between six month LIBOR and three month LIBOR more than doubled from a level of 13.63 basis points on June 28 to 28.25 basis points on June 30 (see Panel A of Figure 1). The implication is clear: lenders in the interbank market wanted a premium to lend cash when the loan was due near the Millennium Date Change.

In addition, as may be seen in Panel A of Figure 1, the term spread widened to a level as high as 42.75 basis points as of September 28, 1999. Then, the spread dropped precipitously by 54.75 basis points to -12.00 basis points the very next day, due to the ballooning of the three-months LIBOR.⁶ This drop reflects the fact that the three-months LIBOR rate as of September 29, 1999 applies to loans that mature very close to the Millennium Date Change! From Panel A of Figure 1, we also see that the term spread reverted back to “normal” levels after the Millennium Date Change.

The term spread between three-month cash LIBOR and one-month cash LIBOR (See Panel B of Figure 1) demonstrates the same sudden change in spreads. This term spread stood at 12.88 basis points on September 28, 1999 and then more than quadrupled to 67.88 basis points on September 29, 1999. The term spread then reached a level of 49.88 basis points on November 26, 1999 only to drop to a level of -36.63 basis points on November 29, 1999. Similar patterns occur in the spread between three-month and one-week LIBOR rates (see Panel C of Figure 1). The spread jumped up one month before the Millennium Date

⁵During the second half the central bank also increased the target rate by a total of 75 basis points. This may also explain a part of the reduced issuance of claims by the private sector.

⁶When comparing the jumps in terms of borrowing costs in dollars, we should control for the differences in the time to maturity of underlying deposits.

Change and dropped one week before the Millennium Date Change.

The jump of the LIBOR term spread related to the year end is unique in 1999. There were no such large jumps in other years. In Panels D, E and F, we plot the spread between the six-month and three-month LIBOR during 1998, 1997 and 1996. It is clear that the changes of the spread at the end of September in 1998, 1997 and 1996 were only small fractions of the change at the end of September in 1999. These graphs indicate that Y2K was the cause of the large jumps in the LIBOR term spread. The most likely interpretation for the jumps is that banks were very reluctant to lend money on loans that matured at the end of 1999.

3.2 Increase of the Cost of Private Loans

As stated earlier, one of the predictions of Holmstrom and Tirole's (1998) model is that private sector claims will be unattractive and expensive as a means to obtain liquidity and liquidity insurance when there is uncertainty about an aggregate shock. To examine this prediction we evaluate the short-term borrowing costs associated with one-month commercial paper issued by AA-rated financial and non-financial companies in the six-month period just prior to the Millennium Date Change. We also examine the behavior of one-month rates on Eurodollar time deposits during the same period.

In interpreting the borrowing costs, it should be kept in mind that the Federal Reserve increased the target rates three times during the second half of 1999. In particular, the target rate was increased by 25 basis points by the Fed on each of the following dates: June 30th, August 24th and November 16th. These Fed actions moved the target rate from 4.75% in the beginning of the year to 5.50% by the end of the year. Hence, rather than focusing on the levels of borrowing costs, we have chosen to work with the spreads over three-month T-bill rates. We used the three-month T-bills in our study because one-month T-Bills were introduced by the Treasury as a benchmark only much later.

Panels A and B of Figure 2 present the cost of obtaining funds for non-financial and financial companies in the commercial paper market around the Millennium Date Change.

During June–November of 1999, the spreads fluctuated between 20 and 74 basis points for non-financial and financial companies. But, beginning on December 1, 1999, the spread for non-financial companies increased dramatically and reached a peak level of 116 basis points on December 27. This is an increase of 84 basis points from a spread of 32 basis points on November 30. The spread for financial companies also increased dramatically in the last month of 1999. It escalated from 31 basis points on November 30 to 114 basis points on December 23. To obtain additional insights on just how costly borrowing was in the private markets, we examine the spread between the rates on one-month Eurodollar time deposits and three-month Treasury bills. We report the spread in basis points in Panel C of Figure 2. It fluctuated between 20 and 77 basis points during June – November of 1999, like the spreads of commercial paper over the T-Bills. The spread then began to widen quickly on December 1 and reached a peak of 131 basis points by December 8, 1999. The spreads remained at a high level until December 28, 1999 and then declined significantly thereafter. We conclude from Panels A, B and C of Figure 2 that the cost of obtaining liquidity in the money markets in the private sector became prohibitively expensive during the period immediately before the Millennium Date Change.

It still remains to be shown that the magnitude of this run-up is high in the period immediately before the Millennium Date Change relative to past year-ends. This is an important issue due to the fact that many institutions clean up their balance sheets and “window dress” them around the end of each year. These transactions typically increase the credit spreads as institutions shed risky assets and acquire higher quality assets around year-end. Such balance-sheet cleaning effects that occur in each year-end should be controlled for in our analysis. Panels D, E and F of Figure 2 illustrate the effect of these transactions by plotting the spread between the rates of non-financial one-month CP and three-month T-Bills for the year-end periods in 1997, 1998 and 1999. The rise of the spread in the last month of 1997 (Panel F) is clearly much smaller than the year-end rise in 1999 (Panel D). The rise of the spread in the last month of 1998 (Panel E) was substantial but still visibly

smaller than the year-end rise in 1999 (Panel D). In the fall of 1998, the markets experienced another liquidity crisis caused by Russian default and the failure of LTCM — these were not anticipated by investors. This pushed the spread above 120 basis points in October of 1998. In 1998, it is possible that companies were more seriously concerned about a liquidity crisis than in the earlier years and thus did more cleaning-up of their balance sheets, causing a bigger year-end effect in the spread.⁷ We will examine the effect of Russian default and the collapse of Long Term Capital Management more explicitly in our econometric work later.

Relative to these year-ending periods, the increase in the CP borrowing rates during the Millennium Date Change was significant from an economic standpoint. To appreciate this, in Table 2 we present the minimum and the maximum of the CP rates in the period covering the year-end. We also indicate the dates on which there was a change in the target Fed funds rate so as to give a broader perspective on our evidence. Note that the rates increased by 48 basis points in 1997, by 67 basis points in 1998 and by a whopping 122 basis points in 1999 — the period immediately prior to the Millennium Date Change. The increase in the cost of obtaining liquidity was much more dramatic in the time leading up to the Millennium Date Change than during the previous year-ends. The CP rates stood at 5.39% when the last target rate increase in 1999 took place on November 16. By December 27, the CP rates had increased to 6.46%, an increase of 107 basis points. Moreover, as noted earlier and documented in Figure 2, the spreads increased much more dramatically during the year end of 1999, as compared to previous year-ends. Based on this evidence, it is reasonable to conclude that the cost of access to liquidity or short-term credit increased significantly in the private markets around the Millennium Date Change, relative to the 1997-1998 experience. This evidence is consistent with the predictions of Holmstrom and Tirole (1996).

By focusing on the commercial paper markets and Eurodollar time deposits, we are

⁷The increased cost of borrowing in the private markets in 1998 is also broadly consistent with the theory on public provision of private liquidity. However, unlike the Y2K crisis in 1999, the date of the potential liquidity shock in 1998 was not foreseeable. Therefore, it does not exactly satisfy the assumptions in Holmstrom and Tirole's model. More importantly, it is impossible for the central bank to issue options on a liquidity event when the date is not foreseeable.

confining attention to top rated borrowers. The results for borrowers with lower credit reputations are very likely to lend additional support in favor of our conclusions.

3.3 Escalation of the Premium of Private Insurance

In the private sector, banks provide loan commitments (LC) to corporations and other financial institutions. The LC is a commitment by the banks to extend loans at a certain fee. Some of the fees are non-contingent (All-in-Undrawn Spread) and some are contingent on drawing the loan (All-in-Drawn Spread). The use of loan commitments as a tool to alleviate liquidity crises has been discussed in a number of papers, including Holmstrom and Tirole (1998). We therefore examine corporate borrowers' costs associated with obtaining loan commitments to backup commercial paper issuance. These costs reflect the insurance premium that commercial banks, acting as financial intermediaries, charge their corporate customers to provide state contingent liquidity. Without such loan commitments it would be difficult, if not impossible, for corporations to access the commercial paper (CP) market. The CP market is a short-term financing mechanism for corporations and financial institutions and ease of access to the CP market is an important measure of liquidity in the private markets.

We collect all loan commitments under the category of 364 days facility that were obtained by corporate borrowers for the sole purpose of backing their commercial paper program. We examine those loan commitments with maturity dates between October 1999 and March 2000. Loan commitments that expired before October and November 1999 would not have enabled the issuers to obtain liquidity a month before the Millennium Date Change. On the other hand, those facilities that matured just before December 1999 and the ones that matured after the Millennium Date Change would have enabled the borrowers to issue commercial paper to cover the Millennium Date Change.

Table 3 reports the price of liquidity insurance during the last quarter of 1999 and the first quarter of 2000 for two categories of borrowers. The key variable is the all-in-drawn

(AID) spread which refers to the ex-ante cost to the borrower for drawing liquidity. The banks charged an all-in-spread of 44.79 basis points for borrowers who were rated below A to provide liquidity insurance to roll over their commercial papers until October 1999. This premium more than doubled to 97 basis points by December 1999. After the Millennium Date Change, the liquidity premium continued to remain at high levels before eventually declining to 73.38 basis points by March 2000. This pattern suggests that not only the actual cost of borrowing in the commercial paper market went up, but also the cost of obtaining liquidity insurance to ensure access to the commercial paper market went up. However, the situation was better for higher quality borrowers who were rated higher than A: there was only a 10 basis points increase in the all-in-spreads on the liquidity drawn from October 1999 to December 1999 for these borrowers.

It is also of interest to note that the all-in undrawn spreads (AIUD) also increased from 4.89 basis points in October 1999 to 7.36 basis points in December 1999 for borrowers rated A or better. The corresponding numbers went from 12.08 basis points in October 1999 to 17.60 basis points in December 1999 for borrowers who were rated below A. This evidence suggests that many issuers found it costlier to access the credit markets just when they might have had a need for it. Examination of the data for a longer time window surrounding Y2K confirms a similar pattern. Moreover, for each day in the quarters around the Millennium Date Change, we calculate the average cost of all the loan commitments that were activated on that day. We find that the AID and AIUD spreads rose before Y2K and then fell shortly after Y2K.⁸ Therefore, the cost of private sector liquidity insurance increased as the Y2K date approached and declined only several weeks after the Millennium Date Change.

3.4 Behavior of the Liquidity Premium in Government Debt

The liquidity premium in government securities has received extensive attention from an empirical perspective. The papers by Kamara (1994), Duffie (1996), Jordan and Jordan (1997),

⁸We do not report these results to conserve space.

Krishnamurthy (2002), Longstaff (2001), Buraschi and Menini (2002) represent some of the earlier contributions. In these papers, the proxy for the liquidity premium in government debt is the spread between the yield to maturity of a newly auctioned government security and that of a government security auctioned earlier. The newly auctioned government security is referred to as on-the-run (OTR) or new bond, while the one auctioned earlier is referred to as off-the-run (OFR) or old bond. With rare exceptions, an OTR bond trades at a yield lower than the yield of similar OFR bond. The level of the spread depends, inter-alia, on the expected auction date and the actual occurrence of the next auction. When the next auction occurs, the current OTR bond becomes the next OFR bond with lower liquidity, and the current OFR bond becomes an even older issue, which has even lower liquidity⁹. The magnitude of the spread between OTR and OFR debt issues and their relationship to auction dates are reported in Sundaresan (1995).

Duffie (1996) relates the liquidity of government securities to their specialness in the repo markets¹⁰. He constructs a model where a bond attracts a higher price if it trades special in the repo markets. He observes that Treasury bonds have different values in the market for collateral — the new bond is generally a more attractive collateral than the old bond. Hence, a new bond commands higher price (or lower yield) relative to the old bond. The collateral value obviously goes up in periods of liquidity crisis thereby resulting in higher OTR-OFR spread.

There is much empirical research demonstrating that the OTR-OFR spread may be a very good proxy for the liquidity premium. For example, Jordan and Jordan (1997) provide evidence supporting this view. Buraschi and Menini (2002) examine the term repo spread, which is regarded as an indicator of the duration of expected specialness in the repo markets. They show that the violation in the expectations hypothesis may be due to the presence of

⁹In a “reopening” auction, in which the supply of an existing issue is increased via auction, this will not be the case.

¹⁰A government security is said to trade “special” in the repo market when the owner of that security is able to pledge it as collateral and borrow money on a short-term basis at interest rates that are considerably lower than the prevailing rates on similar loans collateralized by other government securities.

time-varying liquidity premium in government debt securities. Krishnamurthy (2002) gives a liquidity underpinning in his explanation of the level and variations in the OTR-OFR spread. He does this by exploring the relationship between OTR-OFR spread and the spread between commercial paper and Treasury Bills. Longstaff (2001) demonstrates that the short-term spread is primarily driven by liquidity related factors.

The OTR-OFR spread (adjusted for auction cycle effects) is a relatively clean measure of liquidity premium because the Treasury bonds are default-free and the OTR and OFR bonds are fairly close substitutes in other dimensions. Because the OTR-OFR spread is extensively studied in the literature and is available on high-frequency basis, we will closely examine this measure of liquidity premium in the period around Y2K. An alternative candidate for the measure of the liquidity premium is the difference between general collateral repo rates and special repo rates. Given Duffie's (1996) theoretical arguments and Krishnamurthy's (2002) empirical work, we suspect that using the spread between the general collateral rate and the special repo rate as a measure of liquidity premium will generate qualitatively similar results. Unfortunately, we currently do not have access to historical data for the special repo rates.

The OTR-OFR spread examined in our analysis is the average of the OTR-OFR spreads on five-year and 10-year Treasury notes. The data are a daily time series provided by Lehman Brothers. The 10-year notes are among the most liquid Treasury securities, as has been documented by Fleming (2003). Although the 30-year bond was a major benchmark used in many previous studies, the new issues of 30-year bonds ceased to be liquid in 1999 when the Treasury started to reduce the quantity of new issues of 30-year bonds and planned to initiate a buyback program in response to the projected surplus over the next several years.¹¹ If the data were to include 30-year bonds, it would be hard to tell whether the rise of the liquidity premium is caused by the shrinking supply of 30-year bonds or by the Millennium

¹¹On August 4, 1999, the Treasury announced the consideration of debt buyback program and launched it on January 13, 2000. The first buyback is on March 9, 2000. This possibility was anticipated by the market, although the announcement that issuance of 30-year bonds was suspended came on October 31, 2001. The 30-year bonds were last auctioned in August of 2001.

Date Change. Incorporation of five-year notes in the data offers an inclusive measure of the OTR-OFB spread on medium-term notes. Note that five-year notes have the same quarterly auction cycle as 10-year notes in 1999. In contrast, two-year Treasury notes are auctioned on a monthly basis. The magnitude of the OTR-OFB spread is closely related to auction dates, as demonstrated by Krishnamurthy (2002) and Sundaresan (1995). Exclusion of the two-year notes in the data avoids the difficulty of controlling for the effects of numerous and non-synchronous auction dates.

To examine the behavior of the OTR-OFB spread around the Millennium Date Change, in Figure 3 we plot the OFB-OTR spread during January 1, 1999 – January 31, 2000. The figure shows the auction dates as vertical lines. Disregarding the fluctuations related to the auction cycle, the spreads have an upward trend and peaked during the first half of 1999, but then dropped substantially during the second half. More important, the spread did not rise sharply toward the end of 1999 as the CP-Bills spread did. The behavior of the OTR-OFB spread at the end of 1999 seems contradictory to Holmstrom and Tirole’s (1998) theory. It turned out that the Fed injected a large amount of liquidity near the last few months of 1999 by selling state-contingent claims to the bond dealers. According to Holmstrom and Tirole’s theory, such provision of liquidity should reduce the liquidity premium. Therefore, to understand what happened to the OTR-OFB spread before the Millennium Date Change, we have to examine carefully the provision of liquidity by the Federal Reserve Bank of New York near the end of 1999. This examination is carried out in the rest of the paper.

4 Public Provision of Liquidity Prior to Y2K

4.1 Actions Taken by the U.S. Central Bank

In July of 1999, the U.S. central bank concluded that the Millennium Date Change was likely to lead to liquidity shortages if no actions were taken to prevent them. The central bank was aware of the possibility that customers and bankers might agree to shift settlements

of forward transactions away from the Millennium Date Change period. The information presented in Figure 1 of Section 3.1 was available to the central bank and might have been noted by Fed officials. The U.S. central bank concluded that a) the market may need potentially large year-end reserves, and b) that it would be challenging to meet the need for liquidity in what could be highly illiquid year-end financing markets if dealers and financial intermediaries were to withdraw from important markets such as repurchase agreements during this critical period.

The U.S. central bank responded with several policy initiatives to meet the potential aggregate liquidity shock.¹² First, the central bank extended the maximum maturity of repo operations to 90 days. The purpose of this modification was to meet the year-end seasonal demands and any unusual demands for liquidity beginning as early as October 1999. In addition, this change in maximum maturity allowed the dealers to fund their inventories through the crisis period of the Millennium Date Change. Perhaps the important change was that the central bank eliminated the concern of counterparty default risk by placing itself as counterparty.

The central bank also expanded the menu of collateral in repo transactions to include mortgage-backed securities. This change was motivated by the central bank's desire to expand the pool of assets in its balance sheet. The rationale was to ensure that the potential demanders of liquidity from the central bank are able to deliver securities as collateral in the period of crisis. Restricting the pool of assets that are eligible for collateral in repo transactions would have meant that the central bank might have been unable to add its desired level of reserves to some market segments because players in these segments might have been unable to post collateral. This expansion also reduces the incremental demand on government securities which would putatively trade at a significant liquidity premium during periods of liquidity crisis. These government securities will remain in the market playing a

¹²Descriptions of the actions taken by the Central Bank in this section are largely drawn from "Money Market and the Millennium Date Change," by Peter Fisher, December 1, 1999, the Federal Reserve Bank of New York.

critical role in alleviating the liquidity crisis.

The central bank shifted the normal settlement and custody arrangements for repo transactions to tri-party custodians. The most important aspect of this policy was the fact that the bond dealers and other intermediaries were given greater flexibility to substitute collateral in their repo transactions. This flexibility can be valuable when there is aggregate uncertainty.

Most importantly, the U.S. central bank sold *state-contingent bond contracts*, contracts with terms explicitly specified to be contingent on the economic state around the Millennium Date Change. It was possible because the Millennium Date Change represented one of the few foreseeable states of potential aggregate liquidity shock.¹³ These contracts were options that allowed institutional buyers to exercise in the presence of aggregate liquidity shock around the Millennium Date Change, clearly targeted to meet the potential shortage of liquidity for banks and players in the Treasury bond market. The issuance of these options by the central bank is consistent with the prediction of the Holmstrom and Tirole's (1998) model that state-contingent securities are warranted to mitigate potential liquidity shortages. In the rest of this section, we will describe these options and evaluate their effects on the liquidity premium in the Treasury bond market.

The first option issued by the U.S. central bank was the Special Liquidity Facility (SLF), which was voted on and passed by the Federal Open Market Committee (FOMC) on July 20, 1999, more than five months ahead of the Millennium Date Change. Under the SLF, the depository institutions were allowed to borrow from the Federal Reserve discount window at an interest rate that was 150 basis points above the prevailing federal funds target rate from October 1, 1999 to April 7, 2000. In SLF, depository institutions were given call options for credit on July 20, 1999. The strike of the option was set at 150 basis points above the prevailing federal funds target rate, and it could be exercised during the period from October 1, 1999 to April 7, 2000. By issuing such options, the central bank committed

¹³As noted earlier, year-ends, and major holidays are other states whose timing are known ahead. Seasonal agricultural needs for liquidity are also relatively foreseeable.

itself to provide banks with an alternative source of liquidity for handling potentially large withdrawals (demand for liquidity) of deposits or currencies. This was done to shape the expectations about the availability of year-end liquidity in the money markets.

The Fed reported that there were 14 instances in which depository institutions borrowed from the Special Liquidity Facility for more than ten consecutive days, and another 42 instances of borrowing for two to ten consecutive days. This evidence is consistent with the view that some financial institutions did not have access to market sources of funds at rates less than 150 basis points above the target federal funds rate¹⁴.

The second important policy initiative using option contracts was the commitment to conduct a series of auctions known as the Standby Financing Facility (SFF). These options gave the holders the right, but not the obligation, to execute overnight repo transactions with the New York Fed at a pre-set strike price, which was a financing rate that is 150 basis points above the prevailing federal funds target rate. These options could be exercised during some specified periods around the Millennium Date Change. Under the SFF, demanders of future liquidity were invited to bid for the options at periodic intervals before the Millennium Date Change. The Fed's purpose in issuing these options was to insure that the bond markets operated smoothly around the Millennium Date Change so that the Fed could conduct its monetary policy operations smoothly without running into difficulties. In its August 24 meeting, the FOMC made the necessary rulings to permit the auction of these options.¹⁵

In SFF, the Federal Reserve Bank of New York conducted auctions of the options on the following seven dates in 1999: October 20, October 27, November 3, November 10, November 17, November 23, and December 1. On each of these dates, three options with varying maturity dates were auctioned. The first option allowed the holder to exercise during the period of December 30, 1999 – January 5, 2000, which covered the Millennium Date Change. This option is referred to as “the December 30 strip” by the Federal Reserve

¹⁴Source: *Revisions to Discount Window Programs*, Board of Governors of the Federal Reserve System, October 24, 2002.

¹⁵Source: Press Release by the Federal Reserve Bank of New York on September 8, 1999.

Bank. The second allowed the holder to exercise during the period of December 23, 1999 – December 29, 1999. The third allowed the holder to exercise during the period of January 6, 2000 – January 12, 2000. The last two options are referred to as “the December 23 strip” and “the January 6 strip” respectively. Therefore, there were 21 options in total, 3 on each auction date and 7 for each strip.

We collectively refer to the options in SLF and SFF as Y2K options. Besides the difference in maturity dates, a key distinction between SLF and SFF is that the Y2K options in SLF were issued free of cost to depositary institutions through discount windows while the Y2K options in SFF were sold to Treasury bond dealers for a price. Drossos and Hilton (2000) offer an excellent description of the nature and the purpose of these options contracts. In all of these policy measures, the central bank was acting as a counterparty to the repo transactions as well as to the options transactions. This eliminated counterparty default risk from the perspective of the dealers and banks. In a period of liquidity crisis, this default risk is clearly an important consideration for banks and dealers.

4.2 The Demand and Supply of Y2K Options

How strong was the demand for public provision of private liquidity around the Millennium Date Change? To address this question, we examine the results of the auctions of Y2K options in SFF. Based on the auctions results provided by the Federal Reserve Bank of New York, we estimate the demand functions of Y2K options in each auction. We use the standard demand function with constant elasticity. The functional form is $Q = e^a P^{-b}$, where Q is the quantity of the Y2K options quoted in billions of dollars of repurchase agreements and P is the price of the Y2K options quoted in basis points. For example, for a Y2K option on \$1 billion of overnight repurchase agreement ($Q = 1$), one basis point ($P = 1$) represents an option premium of about \$278 for the option¹⁶.

We estimate the parameters a and b from the regression: $\ln(Q_i) = a - b \ln(P_i) + \epsilon_i$,

¹⁶One basis point on \$1 billion on an overnight basis is worth: $\$1,000,000,000 \times (1/360) \times (1/100) \times (1/100) = \278

where Q_i is the total quantity bid at prices lower than or equal to price P_i . The parameter a measures the aggressiveness of the demand because larger a implies a higher quantity demanded for a given price. The parameter b is the demand elasticity, which measures the sensitivity of quantity to price changes. The assumption of constant price elasticity is motivated not only by simplicity but also by the fact that we had a problem with small sample size: the relatively small number of bids in each auction would have rendered the estimation of a more general demand curve difficult.

The auctions of Y2K options are uniform-price auctions, as in the current auctions of Treasury debt. The supply in each auction is the total amount accepted in the auction. This amount is announced before each auction. However, the result of an auction might have affected the amount the Fed planned to accept in the next auction. According to Drossos and Hilton (2000), the Fed increased the quantities in the second and the third auctions because the demand at the first round of auctions surpassed the Fed's expectations. The price determined by the supply and demand in the auction is referred to as the stop-out rate. The stop-out rate contains useful information about the liquidity demand since the bidders bid *after* the supply is announced by the central bank. The higher the stop-out rate that the bidder is willing to pay for buying the option on liquidity, the greater the demand for the public provision of private liquidity.

In Table 4, we provide the total amount of the bid, the accepted amount, the ratio of accepted amount to total amount, the stop-out rate, the demand aggressiveness, and the demand elasticity, for each auction of each strip of Y2K options. For the December 30 strip, we plot the estimated demand curves in the seven auctions (Figure 4). The accepted amount (supply) is indicated by the vertical line that meets the demand curve, and a horizontal line indicates the stop-out rate. We plot the demand and supply only for the December 30 strip because this strip is far more important than the other two strips.

From Table 4, we see that, on each auction date, the demand for the December 30 strip is always more aggressive than the demand for the other two strips. Recall that Y2K options

of the December 30 strip could be exercised in the week that covers the Millennium Date Change while the Y2K options of the other two strips could not be exercised during this period. Therefore, the Y2K concerns brought about strong demand for the December 30 strip of the Y2K options. We also see that, on each auction date, the stop-out rate for December 30 strip was substantially higher than the stop-out rates for the other two strips. This is also consistent with the strong demand for the December 30 strip. It suggests that concern about the Millennium Date Change was the main reason for the premium on the Y2K options.

The aggressiveness of the demand for the December 30 strip was high on October 27 and November 3. Correspondingly, the stop-out rate for the December 30 strip was also high on these dates. Therefore, the stop-out rates reflect the strength of the demand to some extent, although they are also heavily affected by the supply. To satisfy the demand for liquidity, the Fed adjusted the supply after each auction. These adjustments in supply might have affected the stop-out rates as well.

The aggressiveness of the demand for the December 30 strip started to diminish in the last three auctions. The same is true for the stop-out rates, even though the Fed reduced the supply. The low stop-out rates on the last three auction dates seem to indicate that, to a large extent, the demand for Y2K options had been satisfied by the Fed in prior auctions. Consistent with this view, the demand curves for the last three auction dates plotted in Figure 4 clearly show a significant drop.

4.3 Econometric Models for the Effects of Y2K Options

As we have shown in Section 3.4, the OTR-OFB spread is an extensively used measure of the liquidity premium in the Treasury bond market. Since the Fed used Y2K options to inject a large amount of liquidity to the Treasury bond market, it is natural to examine the effects of Y2K options on the OTR-OFB spread. This also offers a unique opportunity to test Holmstrom and Tirole's (1998) theory on the use of state-contingent government security to

provide liquidity during the crisis of anticipated aggregate shock. We therefore test whether the issuance of Y2K options reduced the OTR-OFR spread.

To examine the effects of Y2K options on the OTR-OFR spread during January 1, 1999 – January 31, 2000, we need to control for other factors that may affect the OTR-OFR spread. To do this, we need a basic model for the behavior of the spread. Our basic model is essentially the one used by Krishnamurthy (2002), which accounts for auction cycle, the supply of Treasury securities and the liquidity premium in the general cash markets. The variables in Krishnamurthy’s model are as follows. On date t , let TLR_t be the relative time to the next auction date of Treasury bond. Specifically, it is defined as

$$TLR_t = \frac{\text{number of days from date } t \text{ to next auction}}{\text{number of days from last auction to next auction}} . \quad (1)$$

Krishnamurthy’s model also allows nonlinear effects of the auction cycle and thus includes the square of the cycle, $TSQ_t \equiv TLR_t^2$, as a variable. Another important variable is the liquidity risk in the general cash markets, which is measured by the spread, denoted by CPB_t , between one-month commercial paper and three-month T-bills as in Section 3.2. The liquidity premium of the Treasury market is also closely related to be the supply, denoted by SUP_t , of the on-the-run five-year and 10-year Treasury notes.

Following Krishnamurthy (2002), we allow CPB_t and SUP_t to interact with the auction cycle, and consequently include the following variables:

$$CTL_t \equiv CPB_t \times TLR_t \quad (2)$$

$$CTQ_t \equiv CPB_t \times TSQ_t \quad (3)$$

$$STL_t \equiv SUP_t \times TLR_t \quad (4)$$

$$STQ_t \equiv SUP_t \times TSQ_t . \quad (5)$$

The *basic model* for our analysis of the OTR-OFR spread is then specified as:

$$\begin{aligned} S_t = & \beta_0 + \beta_{TLR} TLR_t + \beta_{TSQ} TSQ_t + \beta_{CPB} CPB_t + \beta_{CTL} CTL_t \\ & + \beta_{CTQ} CTQ_t + \beta_{SUP} SUP_t + \beta_{STL} STL_t + \beta_{STQ} STQ_t + \epsilon_t , \end{aligned} \quad (6)$$

where β_0 is a constant and other β s are coefficients of the variables.

If the Y2K concerns pushed up the liquidity premium, the OTR-OFB spread should drop right after the Millennium Date Change. To incorporate this change in the market on the first day of 2000, we add a dummy variable, denoted by MDC_t . This dummy variable equals zero before the first day of 2000 and equals one after that date. After adding this dummy variable to the basic model, we have

$$\begin{aligned}
S_t = & \beta_0 + \beta_{TLR}TLR_t + \beta_{TSQ}TSQ_t + \beta_{CPB}CPB_t + \beta_{CTL}CTL_t \\
& + \beta_{CTQ}CTQ_t + \beta_{SUP}SUP_t + \beta_{STL}STL_t + \beta_{STQ}STQ_t \\
& + \beta_{MDC}MDC_t + \epsilon_t .
\end{aligned} \tag{7}$$

For convenience, we refer to this model as the *MDC model*. If the Y2K crisis indeed caused the OTR-OFB spread to rise in 1999, we expect the coefficient β_{MDC} to be negative.

The Fed's injection of liquidity satisfied the demand for Y2K options through a series of auctions. As shown in Section 4.2, the data on the auctions of Y2K options allow us to measure the aggressiveness of the demand for liquidity. Our estimates of aggressiveness of demand for liquidity quantifies the seriousness of the concerns of dealers and their customers about the Y2K crisis. We therefore hypothesize that the aggressiveness of the demand for Y2K options is related to the change of the liquidity premium. Hence, if aggressiveness drops after an auction of Y2K options, the OTR-OFB spread should also drop, *ceteris paribus*.

To incorporate the aggressiveness of the demand for the Y2K options into our regression model, we introduce a variable to capture the changes of the demand for the December 30 strip of the Y2K options. On date t , this variable, denoted by SFF_t , equals the aggressiveness of the demand in the next auction of the December 30 strip of the Y2K options. After the last auction of the Y2K options, the variable SFF_t is set to zero. Obviously, the variable SFF_t is a step function of time, which assumes that the aggressiveness of the demand is the same until the next auction of the Y2K options. Although this does not capture the day-to-day changes in the demand for liquidity, it provides an approximation of the change

of the demand during 1999. The approximation is admittedly imprecise but it can still be informative, especially if it is significantly correlated with the OTR-OFR spread after controlling for other factors.

Unfortunately, we cannot estimate the demand for the Y2K options in the SLF because these options are not sold or auctioned to the banks. However, the Y2K options in the SLF could potentially help to relieve some of the risk related to the Y2K crisis. Therefore, we introduce a dummy variable, denoted by SLF_t , that equals zero before the approval of SLF by the FOMC and equals one thereafter.

We extend the MDC model to include SLF_t and SFF_t and refer to the extended model as the *Central Bank Action (CBA) model*. The model is expressed as

$$\begin{aligned}
 S_t = & \beta_0 + \beta_{TLR}TLR_t + \beta_{TSQ}TSQ_t + \beta_{CPB}CPB_t + \beta_{CTL}CTL_t \\
 & + \beta_{CTQ}CTQ_t + \beta_{SUP}SUP_t + \beta_{STL}STL_t + \beta_{STQ}STQ_t \\
 & + \beta_{MDC}MDC_t + \beta_{SLF}SLF_t + \beta_{SFF}SFF_t + \epsilon_t .
 \end{aligned} \tag{8}$$

If the Y2K options helped to reduce the risk of Y2K crisis, the coefficient β_{SLF} should be negative and β_{SFF} should be positive. The coefficient β_{SLF} should be negative because the SLF should have reduced the risk of Y2K crisis and thus should have caused the liquidity premium to decrease. The coefficient β_{SFF} should be positive because more aggressive demand for Y2K options should be associated with a higher liquidity premium.

In our econometric analysis, we assume that the bidding behavior at any single auction of the Y2K options was not part of a broader bidding strategy that took into account any knowledge that there would be future auctions. Unfortunately, due to confidentiality, the auction data provided by the Fed do not allow us to track any individual bidder for strategic bidding behavior. Moreover, there is very little theory available on repeated auctions and how the bidders bid in them. To complicate matters, the Fed was also learning from each auction and dynamically altering the supply.

4.4 Empirical Tests of Y2K Options' Effects

The results estimated from the above models are reported in Table 5. The t -statistics and p -values reported in the table are adjusted for heteroscedasticity and serial correlation as suggested by White (1980) and Newey and West (1987). In the basic model, the effects of auction cycle (i.e., the coefficients β_{TLR} and β_{TSQ}) are insignificant. This is different from the results reported by Krishnamurthy (2002). The spread of commercial paper over T-bills and its interactions with the auction cycle have strong effects on the OTR-OFB spread, i.e., the coefficients β_{CPB} , β_{CTL} and β_{CTQ} are significant. This is consistent with Krishnamurthy's results. However, none of the coefficients related to the supply (i.e., β_{SUP} , β_{STL} and β_{STQ}), is significant. This is inconsistent with Krishnamurthy's results. The inconsistency between our results and Krishnamurthy's indicates that the behavior of the OTR-OFB spread in 1999 was unusual.

In general, we expect the OTR-OFB spread to correlate with CPB_t positively and with SUP_t negatively, but these cannot be seen directly from the signs of the regression coefficients when the CP-Bills spread and the supply interact with the auction cycle. Given the basic model, the effects of CPB and SUP on the OTR-OFB spread at any point are

$$\frac{\partial S_t}{\partial(\text{CPB}_t)} = \beta_{\text{CPB}} + \beta_{\text{CTL}}\text{TLR}_t + \beta_{\text{CTQ}}(\text{TLR}_t)^2 \quad (9)$$

$$\frac{\partial S_t}{\partial(\text{SUP}_t)} = \beta_{\text{SUP}} + \beta_{\text{STL}}\text{TLR}_t + \beta_{\text{STQ}}(\text{TLR}_t)^2. \quad (10)$$

These effects are functions of the auction cycle TLR_t . One way to get a snapshot of the effects of CPB_t and SUP_t is to evaluate the above partial derivatives at the point, denoted by $\overline{\text{TLR}}$, equal to the average of TLR_t . We can calculate the effect of CPB_t at the point of $\overline{\text{TLR}}$ from the estimates in the basic model. The result is -1.69 . The negative sign is the opposite of the effect of CPB_t we generally expect. The effect of SUP_t at $\overline{\text{TLR}}$ is -0.55 . This sign is consistent with the effects we generally expect.

In the basic model, the difference between our results and Krishnamurthy's (2002) are due to the Y2K crisis. After we add the dummy variable MDC_t , the cycle-related coefficients,

β_{TLR} and β_{TSQ} , become significant in the MDC model (their p -values are 0.01 and 0.05 respectively). The variable MDC_t is negative and significant, consistent with the existence of a premium for the Y2K crisis. This is further confirmed by the sharp increase of the adjusted R-squared from 38.52% for the basic model to 55.08% for the MDC model. However, the supply-related coefficients, β_{SUP} , β_{STL} and β_{STQ} , are still insignificant.

The CBA model, which incorporates the effects of the Y2K options, recovers the results reported by Krishnamurthy (2002). In this model, all the coefficients corresponding to the variables in the basic model are significant. The sign of the coefficients β_{SLF} and β_{SFF} are consistent with our theoretical view that the Y2K options in SLF should reduce the OTR-OFB spread and more aggressive demand for the Y2K options should be associated with a larger OTR-OFB spread. These two coefficients are also very significant (the t -statistics for β_{SLF} and β_{SFF} are -9.08 and 4.95 respectively), indicating that the Y2K options issued by the Fed helped to reduce the liquidity premium in the Treasury bond market. More interestingly, the coefficient β_{MDC} is now insignificant, suggesting that the Fed actions might have removed all of the liquidity premium caused by the Y2K crisis. Also notice that the adjusted R-squared of the CBA model is 83.29%, much higher than the R-squareds of the other two models. Therefore, the Y2K concerns and the Fed's provision of liquidity explain the unusual behavior of the OTR-OFB spread in 1999.

Using the estimates in the CBA model, the effects of CPB_t and SUP_t at the point of \overline{TLR} are calculated to be 0.62 and -0.68 respectively. Interestingly, the effect of the CP-Bills spread at the average point of the auction cycle is now positive, and the effect of the supply at the average point of the auction cycle is negative, consistent with our prior belief that higher CP-Bills spread should lead to higher OTR-OFB spread while higher supply should lead to lower OTR-OFB spread.

The focus on data from 1999 may cause some concern because the OTR-OFB spread climbed sharply after the Russian default on August 17, 1998. It is also well known that the rise of the OTR-OFB was one of the major reasons for the collapse of Long Term Capital

Management (LTCM), a hedge fund in Connecticut. After the collapse of LTCM in the fall of 1998, the OTR-OFR spread started dropping. The drop of the OTR-OFR spread from the crisis of Russian default may have coincided with the drop of the OTR-OFR spread in 1999.

To address this concern, we extend our data back to August 17, 1998. It turns out that this is the earliest date on which our data is available because the five-year and 10-year notes had different auction cycle before this date.¹⁷ In Figure 5, we plot the 20-day moving average¹⁸ of the OTR-OFR spread and CP-Bills spread during the period from August 17, 1998 to January 31, 2000. After the Russian default, the CP-Bills spread and the OTR-OFR spread were both trending upward for more than two months. Then, both spreads generally decreased during the first quarter of 1999. The downward trend of the CP-Bills spread and the OTR-OFR spread are probably the reversal of the effect of Russian default. Since we use CP-Bills spread as a regressor, our analysis controls for the effect of general market trend due to the Russian default and other risk factors.

During the summer of 1999, however, both spreads climbed up again. This suggests that the drop in OTR-OFR spreads following the Russian default ended by the summer of 1999. The moving average of the OTR-OFR spread increased sharply until the Fed started issuing Y2K option. The period during which the Fed issued Y2K options is indicated by the shaded area in Figure 5. During this period, the moving average of the OTR-OFR spread plunged from a peak to a trough. Unless the simultaneous drop of OTR-OFR spread with the issuance of Y2K options was simply coincidental, it suggests that the Fed's actions were effective in reducing the liquidity premium. Near the end of 1999, the CP-Bills spread shot up but the rise of OTR-OFR spread was very modest. Therefore, our hypothesis is that the Y2K options contributed to the difference between the two spreads toward the end of 1999.

To check whether our estimates of the Y2K option effects are robust to the Russian de-

¹⁷On the same date, the Treasury conducted an auction of five-year notes and switched the auction cycle from monthly to quarterly so that the five-year and 10-year notes have the same auction cycle. Since then, the five-year notes are typically auctioned one day before the auction of 10-year notes.

¹⁸The graph is qualitatively similar for 10-day or 30-day moving averages.

fault, we repeated our regressions with the data extended back to August 17, 1998. The results are reported in Table 6. The coefficients related to the CP-Bills spread are insignificant in all the models. However, all the coefficients related to the auction cycle and supply are far more significant in the CBA model than they are in the basic model. More importantly, the coefficients (β_{SLF} and β_{SFF}) corresponding to the Fed's actions still have the signs consistent with the theory and remain to be very significant after extending the data. In this respect, our conclusion that the Fed's provision of liquidity reduced the liquidity in the Treasury bond market still holds.

After extending the data, the coefficient β_{MDC} is still negative and significant in the MDC model. In the CBA model, unlike the insignificant β_{MDC} estimated from the data in 1999, the β_{MDC} estimated from the extended data is significant. Then, we cannot conclude that the Fed's action removed all the premium associated with concerns about Y2K. However, the strong effects of Fed's action are evidently robust. Estimated from the extended data, the coefficient of MDC_t and its t -value in the CBA model are only a fraction of those in the MDC model.

5 Conclusion

The actions taken by the central bank to respond to Millennium Date Change, the behavior of borrowing rates in the private sector and the effect of government actions on liquidity premium all point to very consistent support for the economic theory on the public provision of private liquidity. To our knowledge, this paper is the first to apply economic theory to understand the behavior of the liquidity premium, the actions of the central bank during the period leading up to Y2K, and the prices of private sector claims. In this paper, we measure and test the effects of Y2K options, which are state-contingent government debt, issued by the Federal Reserve Bank in the United States. Our study provides the first economic analysis of the impact of events on liquidity in the period leading up to Y2K; it is also the first to provide empirical evidence supporting the theory of public provision of private

liquidity.

Central banks in other countries also took special measures during the Y2K period. For example, the Bank of Canada issued Y2K options that were free of charge to Canadian depository institutions in a manner similar to the SLF provided by the U.S. central bank¹⁹. The Bank of Canada also expanded the range of collateral as the U.S. central bank did. As another example, the Bank of England issued special Treasury bills that matured on December 31, 1999. The Bank of England expanded the maturity date of repo contract to 90 days and the range of collateral.²⁰ To our knowledge, only the U.S. central bank *sold* options on liquidity.

It should be stressed that the effect of Y2K options was mostly on the liquidity premium in the Treasury bond market because Y2K options only injected liquidity to the primary dealers market. The goal of the Fed was to ensure that banks and dealers in the financial markets would not withdraw from the markets around the Millennium Date Change. The goal was not necessarily to reduce the cost of access to unsecured credit markets by private sector entities. Indeed, as shown in the paper, the Millennium Date Change saw an increase in the cost of borrowing for banks and financial and non-financial companies because Y2K options did not provide liquidity to the players in unsecured credit markets such as the CP market or LIBOR.

Our focus on the liquidity in Treasury market and Y2K options can be broadened to studies on many related issues. For example, during a liquidity crisis, an important task for the central bank is to reduce the counterparty credit risk. In fact, when the central bank issues Y2K options and expands repo maturity and collateral, the central bank acts as the counterparty to relieve the credit risk. Therefore, it would be interesting to examine margin borrowing, trade credit, and actions by the central bank during a liquidity shock. Such an examination could be a part of future research in this area. In addition, one could explore other foreseeable potential aggregate liquidity events. One such event might be the

¹⁹Source: Bank of Canada Press Release, September 2, 1999

²⁰Source: The Bank of England Quarterly Bulletin, August and November 1999 issues.

introduction of Euro currency. Moreover, as noted earlier, one could examine year-ends and long holidays for the presence of liquidity premia and the related actions taken by the central bank.

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7 Tables and Figures

Table 1: Net Issuance of Financial Claims in 1999

This table shows the net issuance of financial claims in the four quarters of 1999. Net issuance is reported in billions of U.S. dollars. Proportion is reported as percentage of the total issuance in a quarter. (Source of data: Federal Reserve Flow of Funds)

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter
<i>Corporate Equity:</i>				
Net issuance	-117.9	-64.9	-79.1	-9.2
Proportion	-10%	-7%	-8%	-1%
<i>Bank Loans & Corporate Bonds:</i>				
Net issuance	826.7	576.5	517.1	166.2
Proportion	67%	59%	51%	24%
<i>U.S. Government Securities:</i>				
Net issuance	517	466.8	569.8	527
Proportion	42%	48%	57%	77%
<i>Total Issuance:</i>	1225.8	978.4	1007.8	684

Table 2: Commercial Paper Rates before Y2K

This table shows the maximum and minimum of commercial paper rates in 1997, 1998 and 1999. It also presents the Fed actions on short-term interest rates in these years. (Source of data: Federal Reserve Board of Governors)

Year end	Min rate	Date of min rate	Max rate	Date of max rate	Change of Fed fund target rate	Date of change
1997	5.46%	Oct 09	5.94%	Dec 26	+ 25 bps	Mar 25
1998	4.80%	Nov 28	5.47%	Dec 23	- 25 bps	Sep 29
					- 25 bps	Oct 15
					- 25 bps	Nov 17
1999	5.24%	Oct 22	6.46%	Dec 27	+ 25 bps	Jun 30
					+ 25 bps	Aug 24
					+ 25 bps	Nov 16

Table 3: Costs of Private Sector Liquidity Insurance

This table presents the costs of loan commitment around the end of 1999. All the rates in the table are reported in basis points. AID and AIUD represent all-in-drawn and all-in-undrawn, respectively. (Source of data: Dealscan)

Maturity Month	AID Spread	AIUD Spread
<i>For borrowers rated A or better</i>		
Oct 1999	23.45	4.89
Nov 1999	27.10	7.22
Dec 1999	33.56	7.36
Jan 2000	22.25	
Feb 2000	34.57	7.19
Mar 2000	28.19	6.73
<i>For borrowers rated below A</i>		
Oct 1999	44.79	12.08
Nov 1999	62.14	10.63
Dec 1999	97.00	17.60
Jan 2000	83.13	17.50
Feb 2000	80.00	19.33
Mar 2000	73.38	15.70

Table 4: The Basic Characteristics of the Auctions of Y2K Options

This table presents the basic characteristics of the auctions of Y2K options. The total amount of bids and the accepted amounts are reported in millions of dollars. The stop-out rates are quoted in basis points. (Source of data: Federal Reserve Bank of New York)

	Auctions						
	Oct 20	Oct 27	Nov 03	Nov 10	Nov 17	Nov 23	Dec 01
	December 30 Strip						
Total amount of bids	115.65	146.90	135.75	85.75	82.95	51.10	52.95
Elasticity of demand	1.10	0.92	0.73	0.90	0.53	0.71	1.14
Aggressiveness of demand	5.31	5.85	5.82	5.50	4.43	4.11	4.03
Accepted amount	18.05	25.00	50.00	49.95	30.00	25.00	24.95
Ratio of accepted to total	0.16	0.17	0.37	0.58	0.36	0.49	0.47
Stop-out rate	10.00	15.00	16.00	8.00	8.00	4.00	2.00
	January 6 Strip						
Total amount of bids	66.50	86.00	107.50	65.85	64.00	36.05	43.70
Elasticity of demand	1.71	0.92	0.69	0.40	0.40	0.63	0.65
Aggressiveness of demand	3.90	4.26	4.84	4.41	3.64	3.42	3.71
Accepted amount	12.00	12.00	25.00	40.00	20.00	20.00	15.00
Ratio of accepted to total	0.18	0.14	0.23	0.61	0.31	0.55	0.34
Stop-out rate	3.00	5.00	11.50	2.50	2.50	2.50	4.00
	December 23 Strip						
Total amount of bids	47.75	55.90	77.35	44.00	49.25	27.45	20.20
Elasticity of demand	1.32	0.93	0.57	0.60	1.15	0.53	1.33
Aggressiveness of demand	3.00	3.27	4.01	3.44	3.16	2.79	2.53
Accepted amount	11.95	12.00	20.00	30.00	14.90	10.00	15.00
Ratio of accepted to total	0.25	0.21	0.26	0.68	0.30	0.36	0.74
Stop-out rate	1.50	2.50	11.00	1.00	1.00	1.50	0.50

Table 5: The Effects of Y2K Options

This table presents estimates of the three models of the effects of Y2K options. The estimates are obtained from regressions using the data from January 1, 1999 to January 31, 2000. For each model, the table reports the estimates, t -statistics and p -values of the coefficients, as well as the R -squared and adjusted R -squared. The t -statistics and p -values are adjusted for heteroscedasticity and serial correlation.

	<i>Basic Model</i>			<i>MDC Model</i>			<i>CBA Model</i>		
R-squared (percent):			40.34			56.58			83.97
Adjusted R-squared:			38.52			55.08			83.29
Variables	coeff	t -stat	p -val	coeff	t -stat	p -val	coeff	t -stat	p -val
Constant	-17.38	-1.66	0.10	-14.72	-1.67	0.10	-41.98	-5.04	0.00
TLR	107.79	1.73	0.08	126.66	2.48	0.01	192.77	5.96	0.00
TSQ	-81.43	-1.32	0.19	-107.05	-1.97	0.05	-150.83	-5.12	0.00
CPB	30.17	7.54	0.00	22.42	4.93	0.00	11.59	2.73	0.01
CTL	-99.51	-7.59	0.00	-89.05	-6.08	0.00	-45.06	-3.26	0.00
CTQ	72.94	5.72	0.00	71.47	5.33	0.00	46.27	4.35	0.00
SUP	0.72	1.10	0.27	0.74	1.23	0.22	2.61	4.65	0.00
STL	-4.05	-1.06	0.29	-5.25	-1.63	0.11	-10.58	-4.97	0.00
STQ	2.93	0.78	0.43	4.32	1.28	0.20	7.84	4.17	0.00
MDC				-4.00	-6.03	0.00	0.62	0.82	0.41
SLF							-2.54	-9.08	0.00
SFF							0.50	4.95	0.00

Table 6: Robustness to the Russian Default

This table presents estimates of the three models of the effects of Y2K options. The estimates are obtained from regressions using the data from August 17, 1998 to January 31, 2000. For each model, the table reports the estimates, t -statistics and p -values of the coefficients, as well as the R -squared and adjusted R -squared. The t -statistics and p -values are adjusted for heteroscedasticity and serial correlation.

	<i>Basic Model</i>			<i>MDC Model</i>			<i>CBA Model</i>		
R-squared (percent):			17.31			34.83			55.39
Adjusted R-squared:			15.45			33.18			54.00
Variables	coeff	t -stat	p -val	coeff	t -stat	p -val	coeff	t -stat	p -val
Constant	-20.17	-1.94	0.05	-15.46	-1.73	0.08	-36.05	-4.06	0.00
TLR	118.24	1.93	0.05	128.59	2.49	0.01	191.79	4.91	0.00
TSQ	-90.09	-1.44	0.15	-108.90	-1.94	0.05	-152.67	-3.77	0.00
CPB	3.41	0.78	0.44	2.08	0.49	0.63	-2.91	-0.71	0.48
CTL	-19.34	-1.08	0.28	-21.10	-1.23	0.22	-3.15	-0.19	0.85
CTQ	18.32	1.17	0.24	21.93	1.45	0.15	8.50	0.61	0.54
SUP	1.47	2.18	0.03	1.23	2.00	0.05	2.55	4.18	0.00
STL	-6.33	-1.67	0.10	-6.80	-2.06	0.04	-11.22	-4.33	0.00
STQ	4.54	1.19	0.24	5.45	1.56	0.12	8.53	3.30	0.00
MDC				-4.49	-9.41	0.00	-1.30	-2.19	0.03
SLF							-1.73	-4.33	0.00
SFF							0.40	3.93	0.00

Figure 1: Term Spreads in Interbank Markets

This figure shows various term spreads of the London Interbank Offer Rates (LIBOR). Panels A, B, and C show the term spreads among six-month, three-month, one-month and one-week LIBOR in 1999. Panels D, E, and F show the term spread between six-month and three-month LIBOR in 1998, 1997, and 1996. (Source of data: British Bankers Association)

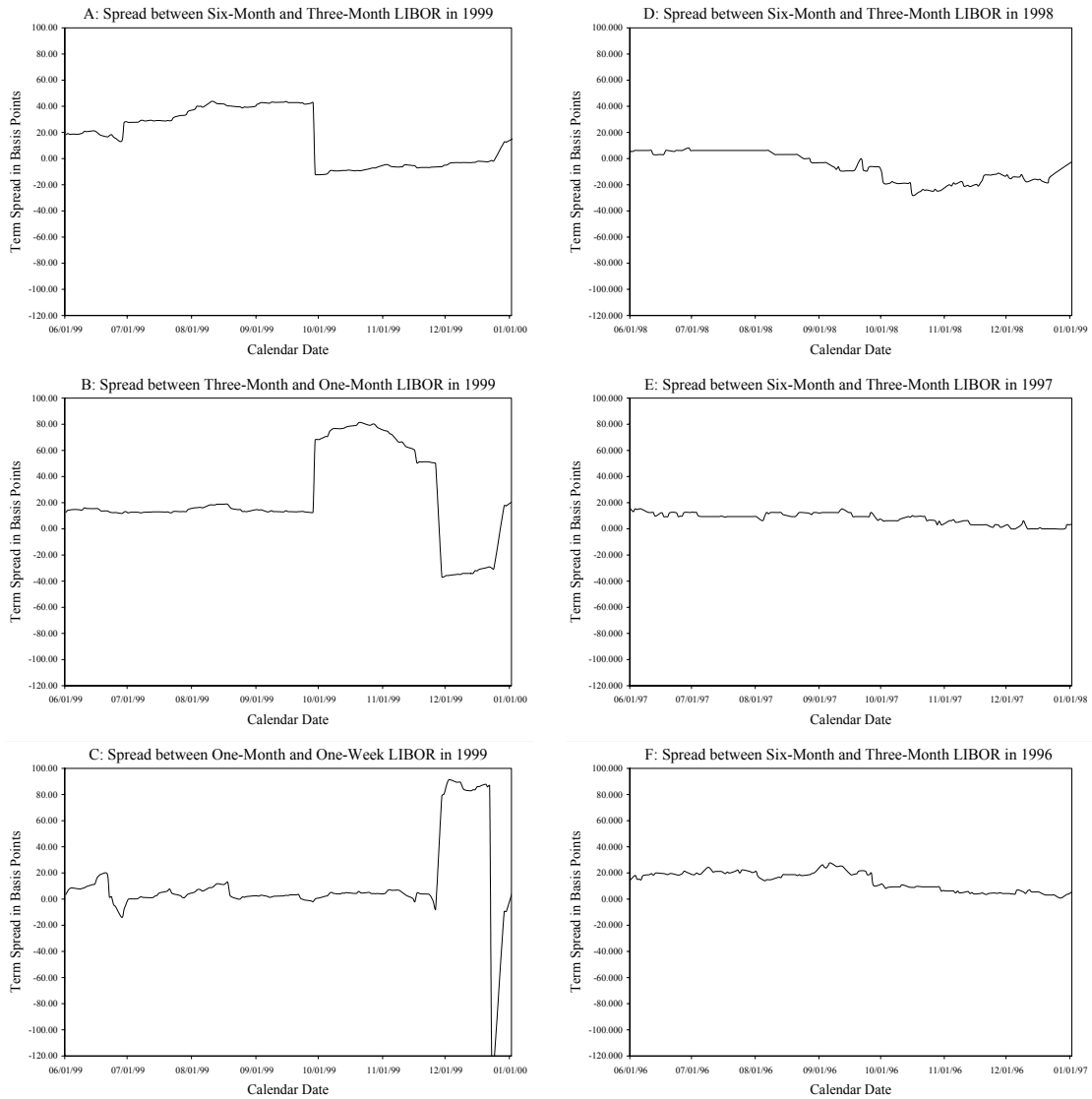


Figure 2: Short-Term Borrowing Costs for Corporations

This figure shows short-term commercial borrowing rates over the Treasury Bills rate. Panels A, D, E, and F are the plots for non-financial commercial papers for various time periods around year ends. Panel B is the plot for financial commercial papers around the end of 1999. Panel C is the plot for Euro-dollar deposit around 1999. (Source of data: Federal Reserve Board and British Bankers Association.)

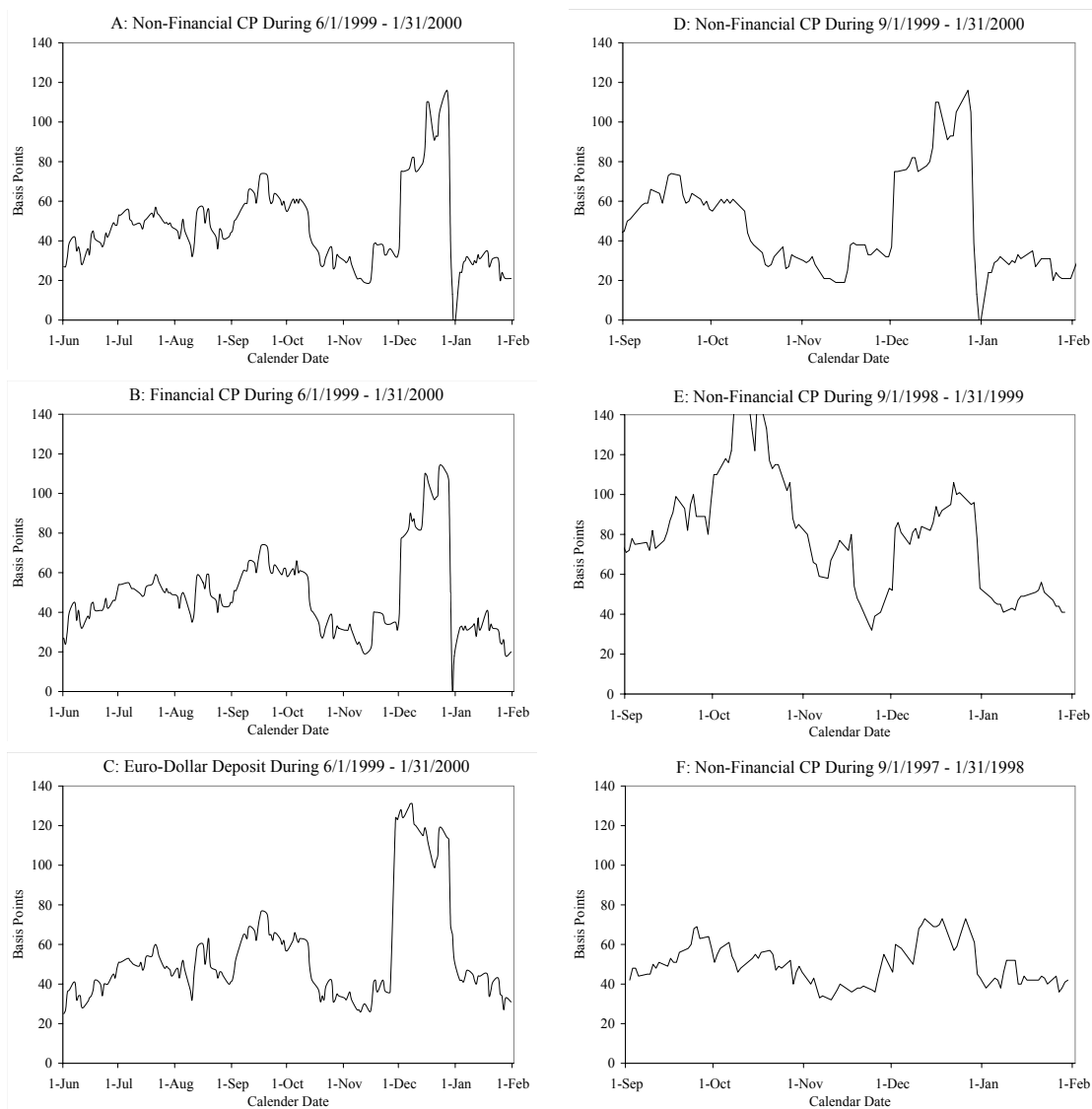


Figure 3: Behavior of the OTR-OFB Spread in 1999

This figure displays the OFB-OTR spread from January 1, 1999 to January 31, 2000. The vertical lines indicate the dates of the quarterly auctions of the five-year and 10-year Treasury notes. (Source of data: Lehman Brothers.)

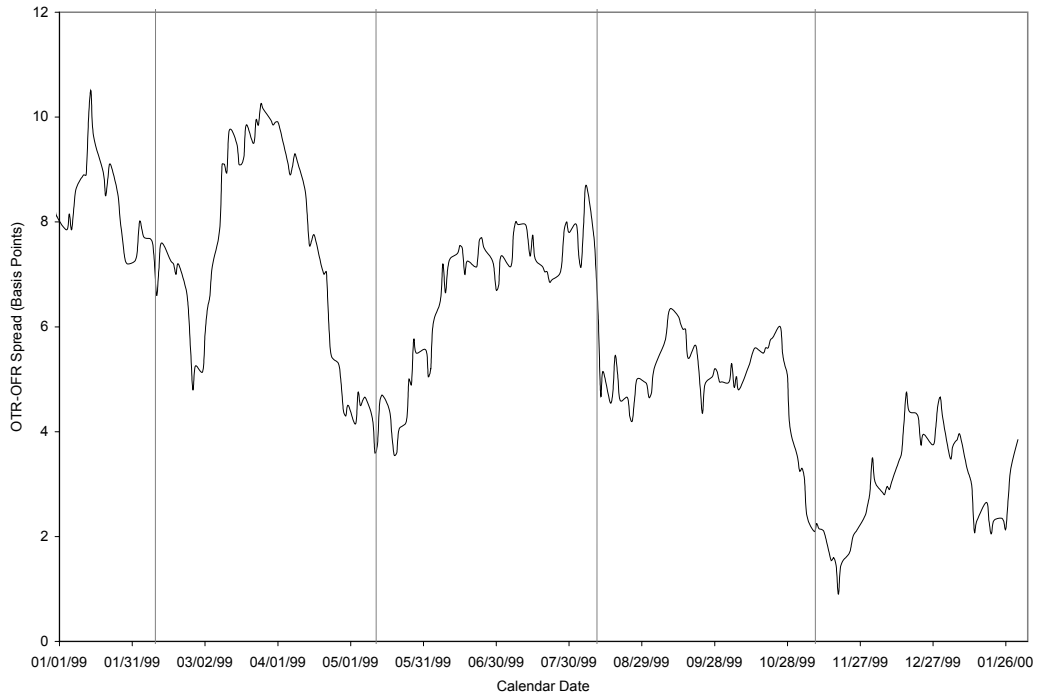


Figure 4: The Demand Curves in the Auctions of Y2K Options

This figure shows the demand and supply in the auctions of the December 30 strip of Y2K options. In each graph, the accepted amount (supply) is indicated by the vertical line that meets the demand curve, and a horizontal line indicates the price (stop-out rate). (Source of data: Federal Reserve Bank of New York)

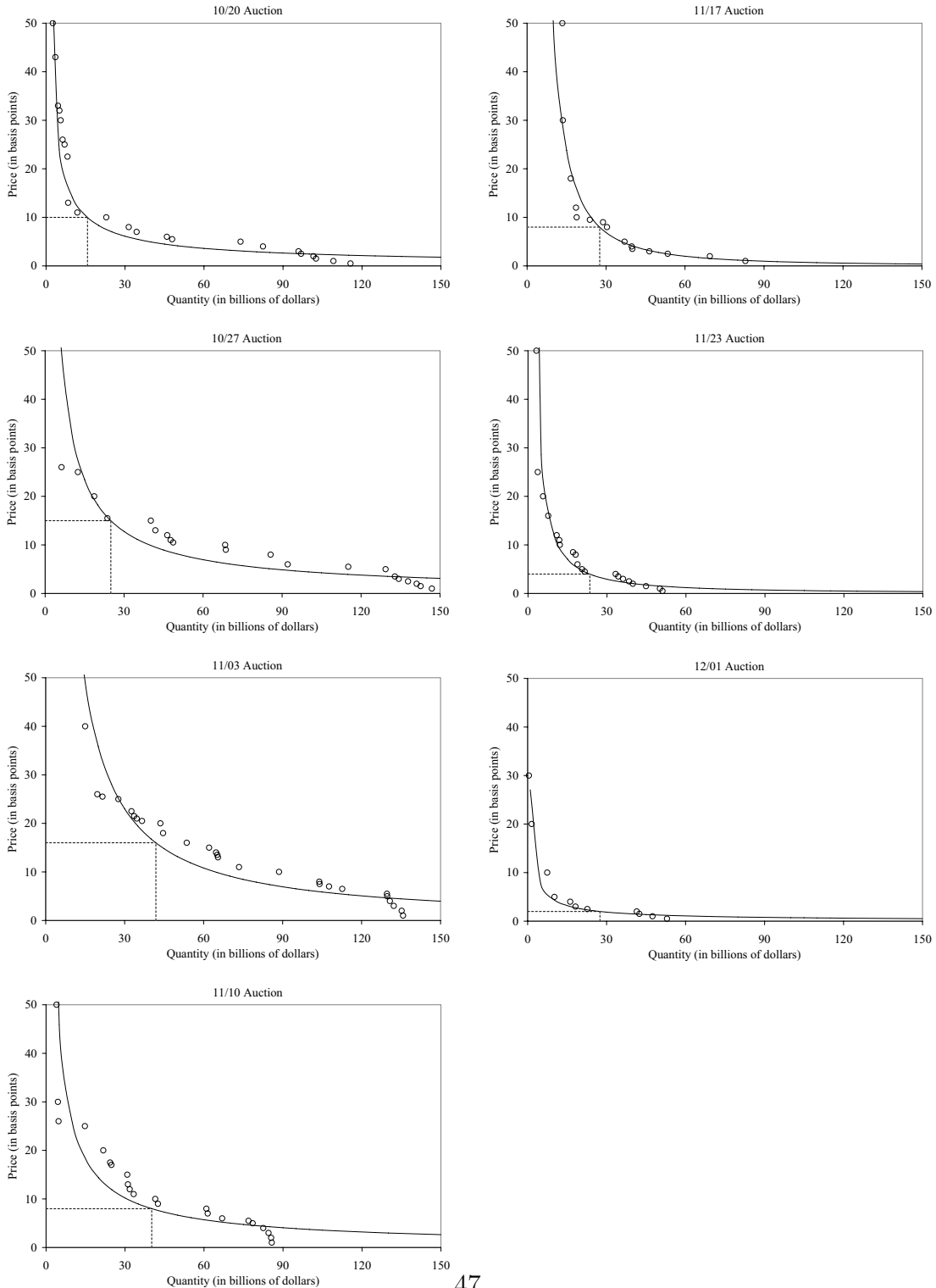


Figure 5: The OTR-OFB Spread Since the Russian Default

The solid curve displays 20-day moving average of the OTR-OFB spread. The OTR-OFB spread is exactly the same as in Figure 3 except that the period extends back to August 17, 1998, on which date the Russian government announced its default on international debt. The dotted curve is the 20-day moving average of the spread between one-month commercial paper rate and the three-month Treasury bill rate. The shaded area indicates the period during which the Fed issued Y2K options. (Source of data: Lehman Brothers and the Federal Reserve Bank of New York)

