

Public Provision of Private Liquidity: Evidence From the Millennium Date Change

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Abstract

The Millennium Date Change (often referred to as Y2K) was anticipated to be a major liquidity event by many financial and corporate institutions as well as the central banks around the world. The timing of the event was foreseeable and thus satisfies the assumptions in the economic theory on public provision of private liquidity. We apply the theory to understand the liquidity premium in financial markets and the actions of the U.S. central bank in the period surrounding Y2K. We demonstrate that in the presence of this potential aggregate liquidity shock, (1) the cost of private loans and insurance increased significantly, (2) government securities commanded a liquidity premium, and most importantly, (3) the Fed successfully provided liquidity insurance and reduced liquidity premium prior to Y2K by taking various actions and especially by issuing Y2K options. These results are consistent with the predictions of the economic theory. Our analysis links the behavior of on/off-the-run spread to the public provision of private liquidity.

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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. 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 period of aggregate liquidity shortage. The supply and demand of liquidity during the crisis 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 during the period surrounding Y2K.

We observe that the potential liquidity crisis associated with the Millennium Date Change represented a liquidity state with a foreseeable date — 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 on the validity of economic theory on public provision of private liquidity. We point out that the central bank’s creation of

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.

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 U.S. in the second half of 1999 helped to reduce the liquidity premium demanded by the market in the period surrounding the Millennium Date Change.

Liquidity provision and 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 the new issues of government debt and the factors that contribute to such premium. Liquidity premium is usually measured by the spread between on-the-run and off-the-run Treasury bonds. This line of enquiry includes the papers by Kamara (1994), Duffie (1996), Jordan and Jordan (1997), Krishnamurthy (2002), Goldreich, Hanke and Nath (2004), etc. Those papers either describe the behavior of the spreads or attempt to explain the presence of the liquidity-related spreads using market prices of other debt securities. In our study of the Y2K crisis, we relate the behavior of on/off-the-run spread (i.e., the 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 private provision of liquidity was prohibitively expensive in the period

surrounding the Millennium Date Change. In Section 4, we document the magnitude and time-variation of liquidity premium in government securities during 1999. In Section 5, we discuss the state-contingent provision of liquidity by the central bank and evaluate its effects on liquidity premium in government debt securities. In section 6 we conclude and point to 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) have explored the topic of 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 to link the presence/absence of liquidity premium in government debt securities to the presence/absence of aggregate liquidity constraints and shocks in the economy. We briefly describe below 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 the increased public debt may increase investment to the extent 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 which then 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 be “special” in the sense that they 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 the 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 its 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 an 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 the private sector firms can raise ex-post. In this sense the private security markets are constrained: 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 in 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 should issue state-contingent securities in anticipation of aggregate liquidity shocks. In Holmstrom and Tirole (1996), they argue as follows: *“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 reality. They identify the reason for their absence as the lack of measurable information about the timing of the aggregate liquidity shocks. They thus make 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 pol-*

icy 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.”

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. Holmstrom and Tirole (1998) in their model assume that the time at which the aggregate uncertainty occurs to be 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, the liquidity shocks in these circumstances are much less severe than Y2K. There is an important difference between such events whose timing is known ahead and other liquidity events such as the Russian default or the collapse of Long-Term Capital Management in August 1998 whose timings were not foreseeable. 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 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 principle our approach can also be used to test the strategies of central banks and the market liquidity premium in year-ends and holidays. But the Millennium Date Change, in our opinion, represented a potential liquidity crisis of far greater magnitude. 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 market prices of private sector claims and government securities during this period.

The quote below by the Chairman of the Federal Reserve illustrates the perception of influential market participants.

“There is nothing exactly like the Century Date Change in our historical annals from which we can infer its potential consequences. ... [T]he response of businesses and households to unwarranted fears of serious disruptions does give me a pause. It is the economic effects of their endeavoring to adjust to the CDC in the next few months that I see as replacing technical concerns as our major challenge. ... If only a small percentage of businesses choose to add to their inventories as a hedge, the effect on production will be insignificant. However, should a large number of companies want to hold even a few extra days of inventories, the necessary, albeit temporary, increase in production (or imports) to accommodate such stock building could be quite large. Bottlenecks could develop, and market pressure could ensue.”

— Alan Greenspan, Chairman, Federal Reserve, September 17, 1999.

Other representatives of the central bank saw elements of “panic” or “extreme risk aversion” in the market.² The economic effects of adjusting to the Millennium Date Change was seen as a major challenge. This perception in addition to other market data, which we summarize later, in turn 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.

Holmstrom and Tirole’s model has several implications to the financial markets around Y2K. First, if no aggregate liquidity shocks are expected to happen at Y2K, their model predicts that the private sector liquidity insurance will be sufficient and there will be no need for the government to provide liquidity. Stated differently, in periods where no aggregate uncertainty is anticipated, government debt securities should not carry any incremental liquidity premium exclusively on this account. Also, if Y2K was not widely viewed as a potential source of aggregate liquidity shock, we should not observe a discount in the prices of private sector securities that is solely attributable to the Y2K date change.

²See Peter Fisher, Money Market and the Century Date Change, Federal Reserve Bank of New York, December,1, 1999.

Second, in the presence of aggregate uncertainty or liquidity shocks related to Y2K, securities issued by private sector entities will be unattractive as means to obtain liquidity insurance. There are two inter-related effects at work here: first, the counterparty default risk will be a major inhibiting factor. This may cause dealers and issuers of private claims to withdraw from the market during the Y2K period. This 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. Second, the withdrawal of dealers from the market may limit the ability of government to intervene to alleviate the liquidity crisis. Hence, the government will have an incentive to intervene ahead. 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.

Third, and perhaps the most important, their model predicts that state-contingent measures by government to alleviate liquidity shortages are generally effective. We will show that this was exactly what happened prior to the Millennium Date Change. Through discount windows, the Federal Reserve Bank of New York offered for free a large amount of liquidity options which matured around the Millennium Date Change. 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 examine the extent to which the state-contingent actions taken by the Fed influenced the liquidity premium in government debt securities. The central bank also introduced 90-days term repo agreements in October 1999 to enable dealers to finance inventories through Y2K without the fear of counterparty default. 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 diminish the liquidity premium in the second half of

1999, just prior to the Millennium Date Change.

3 Private Sector Liquidity Around 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 the 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 1999³. 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 the issuance. Next, as a proportion

³The 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 net new security issuance, government securities represented 77% in the fourth quarter of 1999, which is in sharp contrast to a little over 42% in the first quarter of 1999. This change in the mix of issuance, as well as the change in overall volume, is 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 discourage 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 was clear: lenders in the interbank market wanted a premium to lend cash when the cash was due in the immediate vicinity of the Millennium Date Change.

In addition, as may be noted from 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 3-months LIBOR.⁴ This reflects the fact that the 3-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 evidence is similar when one considers the term spread between 3-month cash LIBOR and 1-month cash LIBOR (See Panel B of Figure 1). 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. One can observe similar phenomenon in the spread between 1-month and 1-week LIBOR rates (see Panel C of Figure 1). The spread jumped up one month before the Millennium

⁴When comparing the jumps in terms of borrowing costs in dollars, we should control for the differences in the time to maturity of underlying deposits.

Date Change and dropped one week before the Millennium Date Change.

The jumps of 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 6-month and 3-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 LIBOR term spread. The most likely interpretation for the jumps is that banks were very reluctant to lend money that matures at the end of 1999.

3.2 Escalation of the Cost of Private Loans

As stated earlier, one of the predictions of Holmstrom and Tirole's model is that the private sector claims will be unattractive and expensive as means to obtain liquidity and its 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. By focusing on the commercial paper markets and Eurodollar time deposits, we are confining attention to top rated borrowers. The results for borrowers with lower credit reputation is likely to lend additional support in favor of our conclusions.

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 a level of 4.75% in the beginning of the year to a level of 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 as one-month T-Bills were

unavailable in 1999 — one-month T-Bills were sold by the Treasury 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 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 get an additional insight on just how costly borrowing was in the private markets, we examine the spread between the rates on one-month Eurodollar time deposits and 3-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 papers 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. They remained at a high level until December 28, 1999 and then declined significantly thereafter. We conclude from Panels A, B and C 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. It is possible that companies were more seriously concerned about liquidity crisis in 1998 than in the earlier years and thus did more cleaning-up of their balance sheets, causing a bigger year-end effects in the spread.⁵

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 year 1999 — the period immediately prior to the Millennium Date Change. The increase in the cost of obtaining liquidity was much more dramatic for the Millennium Date Change than for 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. 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).

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

⁵The 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 Tirol's model. More importantly, it is impossible for the central bank to issue options on the liquidity event when the date is not foreseeable.

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 crisis has been discussed in a number of papers, including Holmstrom and Tirole (1998). We therefore examine the costs associated with obtaining loan commitments for corporate borrowers to backup their commercial paper issuance. These costs reflect the insurance premium that commercial banks 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 1999 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.⁶ Therefore, the cost of private sector liquidity insurance increased as the Y2K date approached and declined only several weeks after the Millennium Date Change.

4 Liquidity Premium of Treasury Debt Around Y2K

4.1 Liquidity Premium of Treasury Debt

Liquidity premium in government securities has received extensive attention from an empirical perspective. The papers by Kamara (1994), Duffie (1996), Jordan and Jordan (1997), Krishnamurthy (2002), Longstaff (2001), Buraschi and Menini (2002) represent some of the earlier contributions. In the literature, an empirical measure of liquidity premium 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

⁶We do not report these results to conserve space.

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 comes, 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 liquidity⁷. 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 markets⁸. 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 is a very good proxy for 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 expectations hypothesis may be due to the presence of 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 strand of the literature on OTR and OFR government bonds, by and large, focuses

⁷In a “reopening” auction, in which the supply of an existing issue is increased via auction, this will not be the case.

⁸A 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.

on the microstructure of the Treasury markets. It does not link the liquidity premium in the Treasury bond market to the demand for and supply of public liquidity in private markets, which are extensively studied in the other strand of the literature represented by the work of Holmstrom, Tirole and Woodford. Nor do any papers on OTR-OFR spread attempt to test the implications of economic theory on the public provision of private liquidity. In the next section, we will bring together the two strands of the literature by explicitly linking the demand for and supply of liquidity to the magnitude of liquidity premium in government debt securities. A major reason for us to examine OTR-OFR spread is that the central bank in U.S. injected a large amount of liquidity into the Treasury bond market in the second half of 1999. This injection of liquidity should directly affect the liquidity premium, the OTR-OFR spread, in Treasury bond market. This allows us to assess the effect of public provision of liquidity before the Millennium Date Change.

The OTR-OFR spread 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 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 the Y2K. An alternative candidate for the measure of liquidity premium is the difference between the general collateral repo rates and the 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 the historical data of the special repo rates.

The OTR-OFR spread examined in our analysis is the average of the OTR-OFR spreads on five-year and ten-year Treasury notes. Ten-year notes are among the most liquid Treasury securities, as has been documented by Fleming (2003). Although the thirty-year bond had been a major benchmark used in many previous studies, the new issues of thirty-year bonds ceased to be liquid in 1999 when the Treasury started to reduce the new issues of thirty-year

bonds and planned to suspend them because of the projected surplus for the next several years.⁹ We therefore decided to exclude 30-year bonds, for it will be hard to tell whether the rise of liquidity premium is caused by the shrinking supply of thirty-year bonds or by the Millennium Date Change. We use the five-year notes to offer a more inclusive measure of the OTR-OFB spread on medium-term notes¹⁰. Note that five-year notes have the same quarterly auction cycle as ten-year notes. 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). To avoid the difficulty of controlling for the effects of numerous auction dates, we do not include two-year notes.

4.2 The Change of Liquidity Premium During 1999

Does the OTR-OFB spread behave differently around the Millennium Date Change than in any typical year? To answer this question, we compare the OFB-OTR spread during this period to its corresponding historical average over the past 14 years (1983–1998). Let the OTR-OFB spread on date t be denoted by S_t . We thus refer to S_t as the spread of 1999 cycle. For each business day t in 1999, we average the OTR-OFB spread on the corresponding business day in the past 14 years. We refer to the average as the spread of past cycle and denote it by \bar{S}_t . The time-series of S_t and \bar{S}_t are plotted in Figure 3. We observe that the OTR-OFB spread S_t in 1999 was mostly higher than the corresponding historical average \bar{S}_t . This seems to indicate a premium associated with Y2K. The pattern reported in Figure 3 is a clear indication that the OTR-OFB in 1999 represented a very different liquidity state compared to the historical average of spreads.

The spread was however much lower in the second half of 1999 than in the first half. As a diagnostic check, we split the year of 1999 into two half-years. During the first half-year,

⁹The thirty-year bond auctions were in fact suspended on January 13, 2000. This possibility was anticipated by the market.

¹⁰Our results do not change qualitatively if only the spread on ten-year notes is used.

the OTR-OFR spread of 1999 cycle was on average much higher than its past cycle (7.18 v.s. 3.02 basis points). This difference shrinks in the second half-year, during which the average of 1999 cycle dropped to 4.99 basis points while the average of the corresponding past cycle stayed above 3 basis points. Note that the correlation between the 1999 cycle with the past cycle was fairly high at 76% in the first half-year. In the second half-year, however, the correlation dropped dramatically to 15%. It appears puzzling that the liquidity premium diminished gradually before the Millennium Date Change. The reduction in the spread before the Millennium Date Change seems to contradict the theoretical implication that Y2K crisis should increase the liquidity premium.

Can factors other than liquidity explain the qualitatively different pattern of the OTR-OFR spreads during the two sub-periods? To test this, we consider the following group of control variables that are often used in empirical studies of the spreads (e.g., see Cortes (2003), for example). An important control variable is the slope of the yield curve which captures market expectations of interest rate risk and changes of investors' risk aversion. We thus use the slope of the yield curve as a control variable in our tests and denote the variable as X_t^{SLP} . To control for the general supply of the bonds, we include a variable, X_t^{SUP} , that represents the change in the amount of U.S. government debt outstanding.¹¹ To control for the general risk in the equity market, researchers often include the volatility index published by the Chicago Board of Options Exchange (CBOE), following the literature. We denote this variable by X_t^{VIX} and obtain the data from CBOE's web site.

We therefore run the following regression:

$$S_t = \mu + \delta \bar{S}_t + \beta_{\text{SLP}} X_t^{\text{SLP}} + \beta_{\text{SUP}} X_t^{\text{SUP}} + \beta_{\text{VIX}} X_t^{\text{VIX}} + \epsilon_t \quad (1)$$

To interpret μ as the average OTR-OFR spread, we demean each independent variable before running the regression. We report the result of the regression in the top panel of Table 4. The average cycle of the spread and the control variables have little or no power to explain

¹¹The data for the slope of the yield curve and the government debt outstanding are obtained from the web site of the Federal Reserve Bank of St. Louis.

the variations in the spread during 1999. The adjusted R-square is only 14%.

To test for the difference between the two sub-periods, we introduce two dummy variables, H_t^1 and H_t^2 . More precisely, $H_t^1 = 1$ if t is before July 1, 1999 and $H_t^1 = 0$ otherwise. The definition for H_t^2 is $H_t^2 = 1 - H_t^1$. We allow the spread to have different means in the two sub-periods. The regression is specified as

$$S_t = \mu_1 H_t^1 + \mu_2 H_t^2 + \delta \bar{S}_t + \beta_{\text{SLP}} X_t^{\text{SLP}} + \beta_{\text{SUP}} X_t^{\text{SUP}} + \beta_{\text{VIX}} X_t^{\text{VIX}} + \epsilon_t . \quad (2)$$

We report the result in the second panel of Table 4. We observe that allowing for different levels in the sub-periods dramatically improves the goodness-of-fit of the regression. The adjusted R-square jumps to 51%. The estimates of μ_1 and μ_2 are very different, with $\mu_1 = 7.75$ and $\mu_2 = 4.42$.

Since the 1999 cycle correlate with the past cycle differently in the two sub-periods, we wanted to test whether the difference in correlation helps to explain the difference in levels. For this purpose, we incorporate the difference in correlation into our regression specification as follows:

$$S_t = \mu_1 H_t^1 + \mu_2 H_t^2 + \delta_1 \bar{S}_t H_t^1 + \delta_2 \bar{S}_t H_t^2 + \beta_{\text{SLP}} X_t^{\text{SLP}} + \beta_{\text{SUP}} X_t^{\text{SUP}} + \beta_{\text{VIX}} X_t^{\text{VIX}} + \epsilon_t . \quad (3)$$

We present the regression result in the third panel of Table 4. We observe that the levels of the spread in the two sub-periods are still very different. As a formal test, the hypothesis of $\mu_1 = \mu_2$ is strongly rejected with an F -value as big as 206.23. The adjusted R-square of the regression increases modestly to 58%. The estimate of δ_2 is only 0.63, consistent with the low correlation in the second half-year that is reported in Figure 3.

These regression results confirm that the OTR-OFR spread behaved very differently in the second half-year of 1999 in comparison to the first half-year. Any explanation of the behavior of the spread has to account for the large difference between μ_1 and μ_2 . If the

Y2K-related liquidity shock was responsible for the high level of the spread during the first half-year, how do we explain the drop in the spread in the second half-year before Y2K? The answer to this question turns to the fact that the central bank in the U.S. took many steps during the second sub-period of 1999 to improve the liquidity of the market and to relieve public concerns about the Y2K crisis. As in Holmstrom and Tirole’s model, the Federal Reserve Bank of New York injected into the bond market a large quantity of contingent claims on liquidity around the Millennium Date Change. In the next section, we will show that the OTR-OFR spreads fell in the second half-year in response to the public provision of private liquidity in the bond market.

5 Public Provision of Liquidity and Y2K Options

5.1 Actions Taken by the U.S. Central Bank

The U.S. central bank concluded as of July 1999 that the Millennium Date Change is likely to lead to liquidity shortages if no actions are taken to prevent it. 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 in Section 3.1 was available to the central bank and noted by Fed officials. The U.S. central bank concluded that a) the market may need potentially large year-end reserve, and b) that there was a challenge in meeting the need in what could be highly illiquid year-end financing markets if dealers and financial intermediaries withdrew 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

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.

demands and any unusual demands for liquidity beginning as early as in October 1999, which was 90 days prior to the Millennium Date Change. In addition, this allowed the dealers to fund their inventories through the Millennium Date Change. Perhaps, more importantly, by placing itself as a counterparty, the central bank eliminated the concern of counterparty default risk.

The central bank also expanded the menu of collateral in repo transactions to include mortgage-backed securities. This was motivated by the desire of the central bank 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 be unable to add its desired level of reserves to certain market segments because players in such segments are 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. Such government securities will remain in the market playing a 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 key dimension of importance in 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 state of potential aggregate liquidity shock.¹³ These contracts are options that allow institutional buyers to exercise at the presence of aggregate liquidity shock around

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.

the Millennium Date Change, clearly targeting to meet 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 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 and passed by the Federal Reserve Board 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 is 150 basis points above the prevailing federal funds target rate from October 1, 1999 to April 7, 2000. Therefore, 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 can be exercised during the period from October 1, 1999 to April 7, 2000. By issuing such options, the central bank committed itself to provide banks 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 second important policy initiative using option contracts was to commit to conduct a series of auctions known as the Standby Financing Facility (SFF). These options give 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 is a financing rate that is 150 basis points above the prevailing federal funds target rate. These options can be exercised during some specified periods around the century 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 of these options is to ensure that the bond markets operate smoothly around the Millennium Date Change so that the Fed can conduct its monetary

policy smoothly without running into difficulties. The Federal Open Market Committee (FOMC) in its August 24 meeting made the necessary rulings to permit the auctions of these options.

In SFF, the Federal Reserve Bank conducted auctions of the options on the following seven dates: October 20, October 27, November 3, November 10, November 17, November 23, and December 1. On each of these dates, three options with different maturity dates were auctioned. The first option allowed the holder to exercise during the period of December 30, 1999 – January 5, 2000, which covers the Millennium Date Change. This option is referred to as “the December 30 strip” by the Federal Reserve 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 was issued free of cost to depository institutions through discount windows while the Y2K options in SFF was 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 these policy measures, the central bank was putting itself as a counterparty to the repo transactions as well as the options transactions. This eliminates the risk of counterparty default risk from the perspective of the dealers and banks. In a period of liquidity crisis, this is clearly an important consideration for banks and dealers.

5.2 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 examined the results of the auctions of Y2K options in SFF. Based on the data 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 ($P = 1$) represented an option premium of about \$278 for the option¹⁴.

We estimate the parameters a and b from the regression: $\ln(Q_i) = a - b \ln(P_i) + \epsilon_i$, 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 its simplicity but also by the fact that we had a problem with small sample size: the 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 results 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 is the demand for the public provision of private liquidity.

In Table 5, we provide the total amount of the bid, the accepted amount, the ratio of

¹⁴One 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

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 that 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 5, 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 can be exercised in the week that covers the Millennium Date Change while the Y2K options of the other two strips cannot be exercised during this period. Therefore, the Y2K concerns manifest themselves into large 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 is substantially higher than the stop-out rates for the other two strips. This is also consistent with the high demand for the December 30 strip. It suggests that the concerns about the Millennium Date Change is the main reason for the premium on the Y2K options.

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

The aggressiveness of the demand for the December 30 strip starts to diminish for the last three auction dates. 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 has been largely 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.

5.3 Evaluating the Effects of Y2K Options

As we have argued earlier, the OTR-OFB spread is a liquidity premium in the Treasury bond market. Since Y2K options injected a large amount of liquidity to the Treasury bond market, it is natural to examine the effect on the OTR-OFB spread. This offers a unique opportunity to test Holmstrom and Tirole's theory on the use of state-contingent government security to provide liquidity and reduce premium in the private markets during the crisis of anticipated aggregate shock. We therefore test whether the issuance of Y2K options reduces the OTR-OFB spread.

Based on the central bank actions related to Y2K, we divide the days of 1999 into 9 sub-periods indexed by numbers from 0 to 8. Each sub-period is bounded by the dates on which actions for the Millennium Date Change were taken by the central bank. To examine the effect of the Millennium Date Change itself, we need to examine the period a little beyond the end of 1999. We thus extend the sample period to include January 2000 and number it as sub-period 9. The exact definitions of the sub-periods are listed below:

- Sub-period 0: Jan 01 – Jul 19 (before the FOMC vote of SLF)
- Sub-period 1: Jul 20 – Oct 19 (after the SLF and before the auctions)
- Sub-period 2: Oct 20 – Oct 26 (after the 1st and before the 2nd auction)
- Sub-period 3: Oct 27 – Nov 02 (after the 2nd and before 3rd auction)
- Sub-period 4: Nov 03 – Nov 09 (after the 3rd and before the 4th auction)
- Sub-period 5: Nov 10 – Nov 16 (after the 4th and before the 5th auction)
- Sub-period 6: Nov 17 – Nov 22 (after the 5th and before the 6th auction)
- Sub-period 7: Nov 23 – Nov 31 (after the 6th and before the 7th auction)
- Sub-period 8: Dec 01 – Dec 31 (after the 7th auction and before Y2K)
- Sub-period 9: Jan 04 – Jan 31 (after Y2K)

Note that the dates of the auctions shown in Table 5 provide a natural way to construct these sub-periods. We choose to use the auction dates to divide the periods because these are the dates on which the bank or dealers acquire Y2K options in their accounts. Although our choice does not allow us to pin down the effect of Fed's announcement prior to each

auction, it allows us to examine the cumulative effect of the announcement of the auctions. In addition, we suspect that the announcement effect is less important than the effect on the auction date because the Fed adjusted and announced the accepted amount (supply) right before each auction.

Figure 5 plots the OTR-OFR spread from January 1, 1999 to January 31, 2000. The shaded area indicates the period of Fed actions from July 20, 1999 to December 1, 1999. The stop-out rates of the seven auctions of the December 30 strip are also plotted along with the spread. The drop of the spread seems to coincide with the Fed actions and the auctions. In the following, we conduct an econometric evaluation of the Fed actions on the OTR-OFR spread.

For econometric tests, we define dummy variable I_t^i as $I_t^i = 0$ if t falls into a period before period i or $I_t^i = 1$ otherwise, for $i = 1, \dots, 9$. The model we use to study the incremental effect of each of the Fed actions is the following regression

$$S_t = \mu + \delta \bar{S}_t + \beta_{\text{SLP}} X_t^{\text{SLP}} + \beta_{\text{SUP}} X_t^{\text{SUP}} + \beta_{\text{VIX}} X_t^{\text{VIX}} + \sum_{i=1}^9 \alpha_i I_t^i + \epsilon_t, \quad (4)$$

which is an extension of regression (1). All variables, except the dummy variables, in the above equation are defined and demeaned as in equation (1). This way of constructing the dummy variables allows us to interpret the slope coefficients, α_i for $i = 1, \dots, 9$, as the incremental effect of each of the dummy variables. Note that each of the first eight dummy variables represents an initiative taken by the central bank. The coefficients of the eight dummy variables, α_i for $i = 1, \dots, 8$, capture the changes in the liquidity premium caused by the Fed actions. To keep things simple, we estimate the regression equation by the ordinary least-squares (OLS).

The results of the regression are presented in Table 6. Our results show that the Fed actions on the Y2K liquidity crisis had significant effects in reducing the OTR-OFR spread. The reduction of the spread caused by the SLF is 1.61 basis points (the estimate of α_1 is -1.61), which is statistically significant after adjusting for errors (p -value of α_1 is almost 0).

The incremental reduction caused by the second and third auctions of the SFF is marginally significant (p -values of α_3 and α_4 are 0.09 and 0.05), but the effect of each of the other five auctions is much less clear. Note that the last target rate increase in 1999 took effect on November 16th, which is just a day prior to the fifth auction. The raise of target rate by the Fed might have counterbalanced the effects of the last three auctions. In Figure 5, during the second half of 1999, the OTR-OFB spread shows a clear downward trend despite the three increases in the target Fed funds rate that took effect during this sub-period.

To examine the cumulative effect of all of the seven auctions of SFF, we test the restriction $\alpha_2 + \dots + \alpha_8 = 0$. The p -value of this test is almost zero and thus we can reliably conclude that the total effect of the seven auctions, along with the other actions taken by the Fed during this period, was significant in reducing the liquidity premium. The estimate of the total change caused by the seven auctions is $\alpha_2 + \dots + \alpha_8 = -2.59$. The estimate of the total change caused by *both* the SLF and SFF is $\alpha_1 + \dots + \alpha_8 = -4.20$, which is significantly different from zero (p -value is almost zero).

Therefore, the Fed's actions on the Y2K crisis significantly reduced the liquidity premium associated with the potential liquidity crisis. Did the Fed succeed in removing all the liquidity premium associated with the Millennium Date Change? To answer this question, we look at the reduction caused by the turn of the Millennium Date Change itself. The reduction was 0.79 basis point (the estimate of α_9 is $-.79$ but significantly different from zero), which was much smaller than the reduction caused by the actions of the Fed. Therefore, we conclude that the Fed's actions removed most the liquidity premium associated with Y2K but not all of it.

We need to link the regression estimates, which reflect the effects of Y2K auctions on the OTR-OFB spread, to the aggressiveness of the demand and the market clearing price of the Y2K options. In Figure 6, we first plot the spread reduction caused by the auctions along with the aggressiveness of the demand. That is, we plot $-\alpha_2, \dots, -\alpha_8$ along with the aggressiveness of demand for each strip over the seven auction dates. Clearly, the spread

reduction is highly correlated with aggressiveness of demand for each strip. The correlation between the spread reduction and the aggressiveness of demand for the December 30 strip is 98.33%. The corresponding correlation estimates for the other strips are only slightly lower. We also plot the spread reduction along with the stop-out rate. Obviously, the spread reduction is big when the stop-out rate is high. The correlation between the spread reduction and the stop-out rate for the December 30 strip is 87.68%. These high correlations confirm that the provision of Y2K options made a difference in alleviating the liquidity premium when the demand was high.

It is reasonable to ask why we do not directly incorporate auctions stop-out rates or demand aggressiveness into the regression model. The econometric problem that we face is the following: the OTR-OFR spread is available to us on a high frequency (daily) basis. On the other hand, the auctions of Y2K options were conducted on a few discrete dates. We have no way of knowing what the stop-out rates and the demand curves might have been had the central bank conducted auctions on all the missing dates. One approach might be to treat all the dates on which there were no auctions as missing observations. This is not desirable as there are too many dates on which there were no auctions. Perhaps, more importantly, the influence of having auctions only on discrete dates is to make the incremental effect of each auction much more significant than would be the case if one were to assume there were continuous auctions on which we have missing observations. We therefore use the proposed method outlined in equation (4) but circle back to interpret our empirical finding by linking them to the results of the SFF auctions.

In our econometric analysis, we assume that bidding behavior at any single SFF auction was not part of a broader bidding strategy that took account of knowledge that there would be future SFF 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, Fed was also learning from each auction and dynamically

altering the supply.

We conclude that the OTR-OFB spread in the first half of 1999 contained a liquidity premium associated with Y2K and that the issuance of Y2K options during the second half of 1999 removed most of the premium. This explains why the OTR-OFB spread was systematically higher than the historical average during the first half of 1999, but not during the second half of 1999. To confirm this, we add the 8 dummy variables of Y2K options to the regression equation (3). The resulting regression is

$$\begin{aligned}
 S_t = & \mu_1 H_t^1 + \mu_2 H_t^2 + \delta_1 \bar{S}_t H_t^1 + \delta_2 \bar{S}_t H_t^2 \\
 & + \beta_{\text{SLP}} X_t^{\text{SLP}} + \beta_{\text{SUP}} X_t^{\text{SUP}} + \beta_{\text{VIX}} X_t^{\text{VIX}} + \sum_{i=1}^8 \alpha_i I_t^i + \epsilon_t .
 \end{aligned} \tag{5}$$

As in Section 4.2, the sample period of the regression covers only the days in 1999. The estimation and tests related to the above regression are reported in Table 7. After introducing the dummy variables for Y2K events, μ_1 and μ_2 are almost exactly the same! This further demonstrates that the premium and events associated with Y2K caused the OTR-OFB spreads to be different during the two sub-periods of 1999. It is important to note that the effects of most Y2K options remain similar to the effects seen in the regression equation (4). During the second half-year of 1999, the success of Y2K options destroyed the typical seasonal pattern of the OTR-OFB spread. This explains why the correlation between the OTR-OFB spread and its past average broke down in the later part of 1999.

6 Conclusion

The actions taken by the central bank to respond to Millennium Date Change, the behavior of borrowing rates in the private sector, the value of loan commitments, and the effect of government actions on liquidity premium all point to a very consistent support for the economic theory on public provision of private liquidity. To our knowledge, this paper is the first to apply the economic theory to understand the behavior of liquidity premium, the actions of the central bank during the Y2K crisis, and the volume and prices of private

sector claims. In this paper, we measure and test the effects of Y2K options, which are state-contingent government debts, issued by the Federal Reserve Bank in the United States. Our study provides the first 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, Bank of Canada issued Y2K options free of charge to Canadian depository institutions in a manner similar to the SLF provided by the U.S. Central Bank¹⁵. Bank of Canada also expanded the range of collateral as the U.S. Central Bank did. As another example, Bank of England issued special Treasury bills that matured on December 31, 1999. Bank of England expanded the maturity date of repo contract to 90 days and the range of collateral.¹⁶ 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 will 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. This does not contradict the view that liquidity premium will decline in the private market if the government injects liquidity in the crisis of aggregate liquidity shock.

Our focus on the liquidity in Treasury market and Y2K options can be broadened to studies on many related issues. For example, in the crisis of liquidity shock, an important task for the central bank is to reduce the counterparty credit risk. In fact, when the central bank issue Y2K options and expand repo maturity and collateral, the central bank put itself

¹⁵Source: Bank of Canada Press Release, September 2, 1999

¹⁶Source: Bank of England Quarterly Bulletin, August and November 1999 issues. We thank B. P. A. Andrews of Bank of England for bringing to our attention the actions taken by the Bank of England.

as the counterparty to relieve the credit risk. Therefore, it will be interesting to examine the margin borrowing, the trade credit, and the market bid-ask spread during the crisis of the liquidity shock and actions by the central bank. These examinations can be interesting future research. In addition, we should explore other foreseeable potential aggregate liquidity events. One such event might be the introduction of Euro currency. Moreover, as noted earlier, one could examine year-ends and long holidays for the presence of liquidity premium and actions taken by the central bank.

7 References

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8 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	517.0	466.8	569.8	527.0
Proportion	42%	48%	57%	77%
Total Issuance:	1225.8	978.4	1007.8	684.0

Table 2: Commercial Paper Rates before Y2K

This table shows the maximum and minimum of the 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	Fed Actions
1997	5.46%	October 9	5.94%	December 26	+ 25 bps (March 25)
1998	4.80%	November 28	5.47%	December 23	-25 bps (September 29) -25 bps (October 15) -25 bps (November 17)
1999	5.24%	October 22	6.46%	December 27	+ 25 bps (June 30) + 25 bps (August 24) + 25 bps (November 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 for 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>		
October 1999	23.45	4.89
November 1999	27.10	7.22
December 1999	33.56	7.36
January 2000	22.25	
February 2000	34.57	7.19
March 2000	28.19	6.73
<i>For borrowers rated below A</i>		
October 1999	44.79	12.08
November 1999	62.14	10.63
December 1999	97.00	17.60
January 2000	83.13	17.50
February 2000	80.00	19.33
March 2000	73.38	15.70

Table 4: Tests for the Changes of the OTR-OFR Spread During 1999

This table presents the OLS (ordinary least squares) estimates of regressions (1), (2) and (3). The last regression is also used to test whether the behavior of the OTR-OFR spread changed during the first and second half year of 1999.

Coefficient	Estimate	Stderr	<i>t</i> -stat	<i>p</i> -value
Regression (1)				
μ	6.08	.12	48.82	.00
δ	1.04	.24	4.35	.00
β_{SLP}	.29	.72	.40	.69
β_{SUP}	-.03	.02	-1.78	.08
β_{VIX}	.22	.04	5.20	.00
$R^2 = 15.80\%$		Adjusted $R^2 = 14.43\%$		
Regression (2)				
μ_1	7.75	.15	50.33	.00
μ_2	4.42	.15	28.84	.00
δ	2.26	.20	11.24	.00
β_{SLP}	3.20	.59	5.46	.00
β_{SUP}	-.02	.01	-1.40	.16
β_{VIX}	.07	.03	1.93	.05
$R^2 = 52.32\%$		Adjusted $R^2 = 51.35\%$		
Regression (3)				
μ_1	7.97	.15	53.86	.00
μ_2	4.71	.15	31.29	.00
δ_1	3.10	.23	13.35	.00
δ_2	.63	.32	1.95	.05
β_{SLP}	4.30	.58	7.48	.00
β_{SUP}	-.01	.01	-1.35	.18
β_{VIX}	.09	.03	2.64	.01
$R^2 = 58.71\%$		Adjusted $R^2 = 57.69\%$		
Hypothesis	<i>F</i> -value	<i>p</i> -value	Difference	
$\mu_1 - \mu_2 = 0$	206.23	.00	3.26	
$\delta_1 - \delta_2 = 0$	37.74	.00	2.47	

Table 5: 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						
	10/20	10/27	11/03	11/10	11/17	11/23	12/01
	December 30 Strip						
Total amount of bids	115,650	146,900	135,750	85,750	82,950	51,100	52,950
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	18,050	25,000	50,000	49,950	30,000	25,000	24,950
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	66,500	86,000	107,500	65,850	64,000	36,050	43,700
Elasticity of demand	1.71	0.92	0.69	0.86	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	12,000	12,000	25,000	40,000	20,000	20,000	15,000
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	47,750	55,900	77,350	44,000	49,250	27,450	20,200
Elasticity of demand	1.32	0.93	0.57	0.62	1.15	0.53	1.33
Aggressiveness of demand	3.00	3.27	4.01	3.48	3.16	2.79	2.53
Accepted amount	11,950	12,000	20,000	30,000	14,900	10,000	15,000
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 6: Tests of Effects of Y2K Options on the OTR-OFB Spread

This table presents the OLS (ordinary least squares) estimates of regression (4). The regression gives the change (α_i for $i = 1, \dots, 8$) of the OTR-OFB spread associated with each of Fed's action using Y2K options. It also shows the results of tests for related null hypothesis.

Coefficient	Estimate	Stderr	<i>t</i> -stat	<i>p</i> -value
μ	7.40	.11	67.82	.00
δ	1.31	.16	8.36	.00
β_{SLP}	-1.30	.57	-2.29	.02
β_{SUP}	.00	.01	-.23	.82
β_{VIX}	-.01	.03	-.34	.73
α_1	-1.61	.22	-7.30	.00
α_2	-.52	.56	-.93	.36
α_3	-1.28	.76	-1.68	.09
α_4	-1.51	.76	-1.99	.05
α_5	-1.21	.81	-1.50	.14
α_6	.22	.85	.25	.80
α_7	.96	.80	1.19	.23
α_8	.76	.60	1.26	.21
α_9	-.79	.39	-2.04	.04
$R^2 = 72.43\%$		Adjusted $R^2 = 71.03\%$		
Hypothesis	<i>F</i> -value	<i>p</i> -value	Difference	
$\alpha_i = 0$ for $i = 1, 8$	52.78	.00		
$\sum_{i=1}^8 \alpha_i = 0$	197.03	.00	-4.20	
$\alpha_i = 0$ for $i = 2, 8$	15.75	.00		
$\sum_{i=2}^8 \alpha_i = 0$	53.66	.00	-2.59	

Table 7: Explaining the Changes of the OTR-OFB Spread by Y2K Options

This table presents the OLS (ordinary least squares) estimates of regression (5). In addition to estimating the change (α_i for $i = 1, \dots, 8$) of the OTR-OFB spread associated with each of Fed's action using Y2K options, it tests whether the behavior of the OTR-OFB spread is different during the first and second half year of 1999 after controlling for the Fed actions.

Coefficient	Estimate	Stderr	<i>t</i> -stat	<i>p</i> -value
μ_1	7.70	.12	65.50	.00
μ_2	7.64	.38	20.00	.00
δ_1	2.41	.19	12.42	.00
δ_2	-.32	.28	-1.12	.26
β_{SLP}	.76	.58	1.31	.19
β_{SUP}	-.01	.01	-.68	.50
β_{VIX}	.02	.03	.67	.50
α_1	-1.92	.39	-4.92	.00
α_2	.10	.51	.20	.84
α_3	-1.50	.69	-2.18	.03
α_4	-1.58	.69	-2.30	.02
α_5	-.58	.73	-.79	.43
α_6	-.67	.78	-.86	.39
α_7	.75	.73	1.03	.31
α_8	1.74	.56	3.12	.00
$R^2 = 75.96\%$		Adjusted $R^2 = 74.53\%$		
Hypothesis	<i>F</i> -value	<i>p</i> -value	Difference	
$\mu_1 - \mu_2 = 0$.02	.88	.06	
$\delta_1 - \delta_2 = 0$	63.05	.00	2.73	
$\sum_{i=1}^8 \alpha_i = 0$	73.36	.00	-3.67	
$\sum_{i=2}^8 \alpha_i = 0$	27.21	.00	-1.75	

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 6-month, 3-month, 1-month and 1-week LIBOR in 1999. Panels D, E, and F show the term spread between 6-month and 3-month LIBOR in 1998, 1997, and 1996. (Source of data: British Bankers Association)

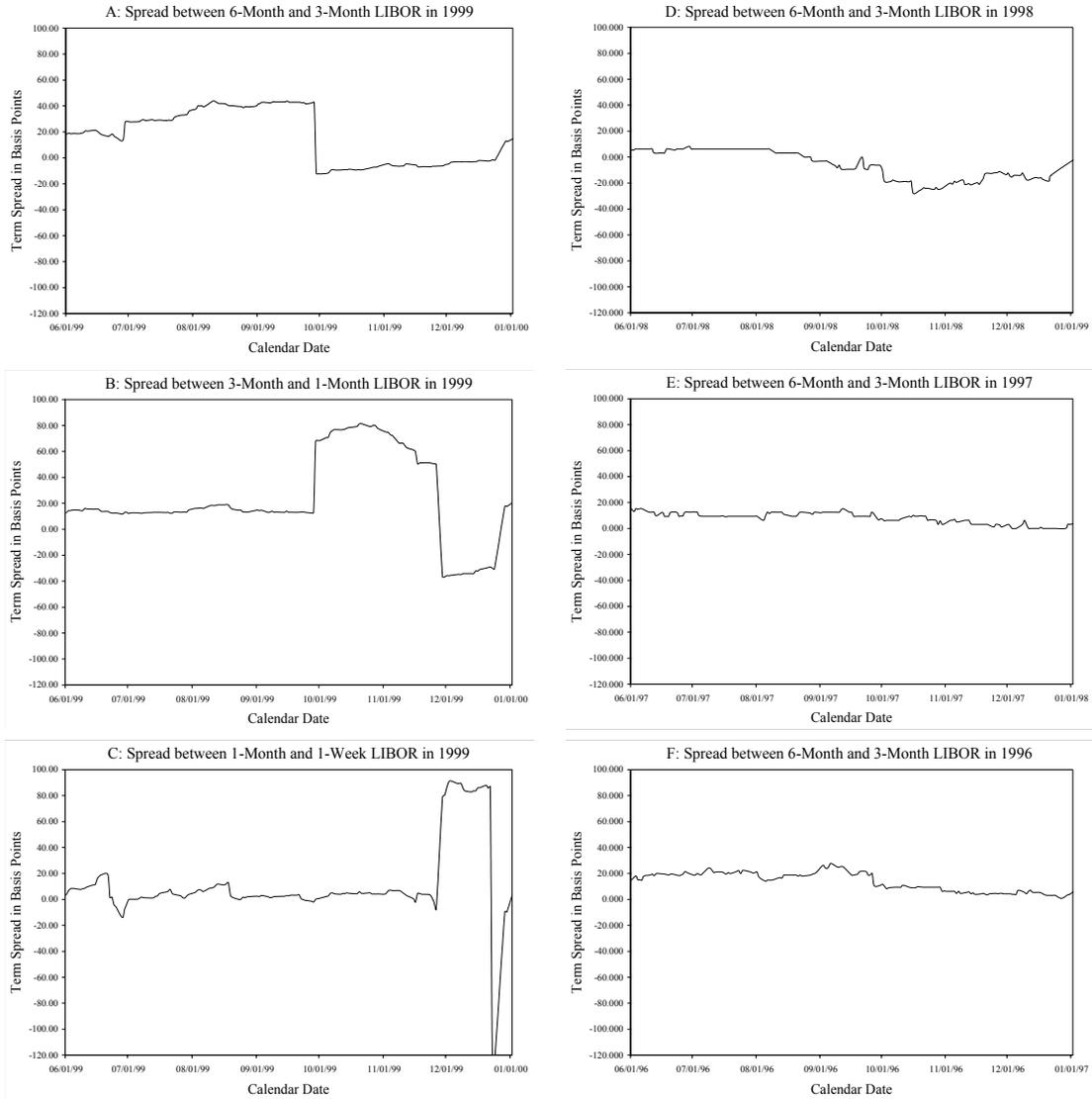


Figure 2: Short-Term Borrowing Costs for Corporations

This figure shows the 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.)

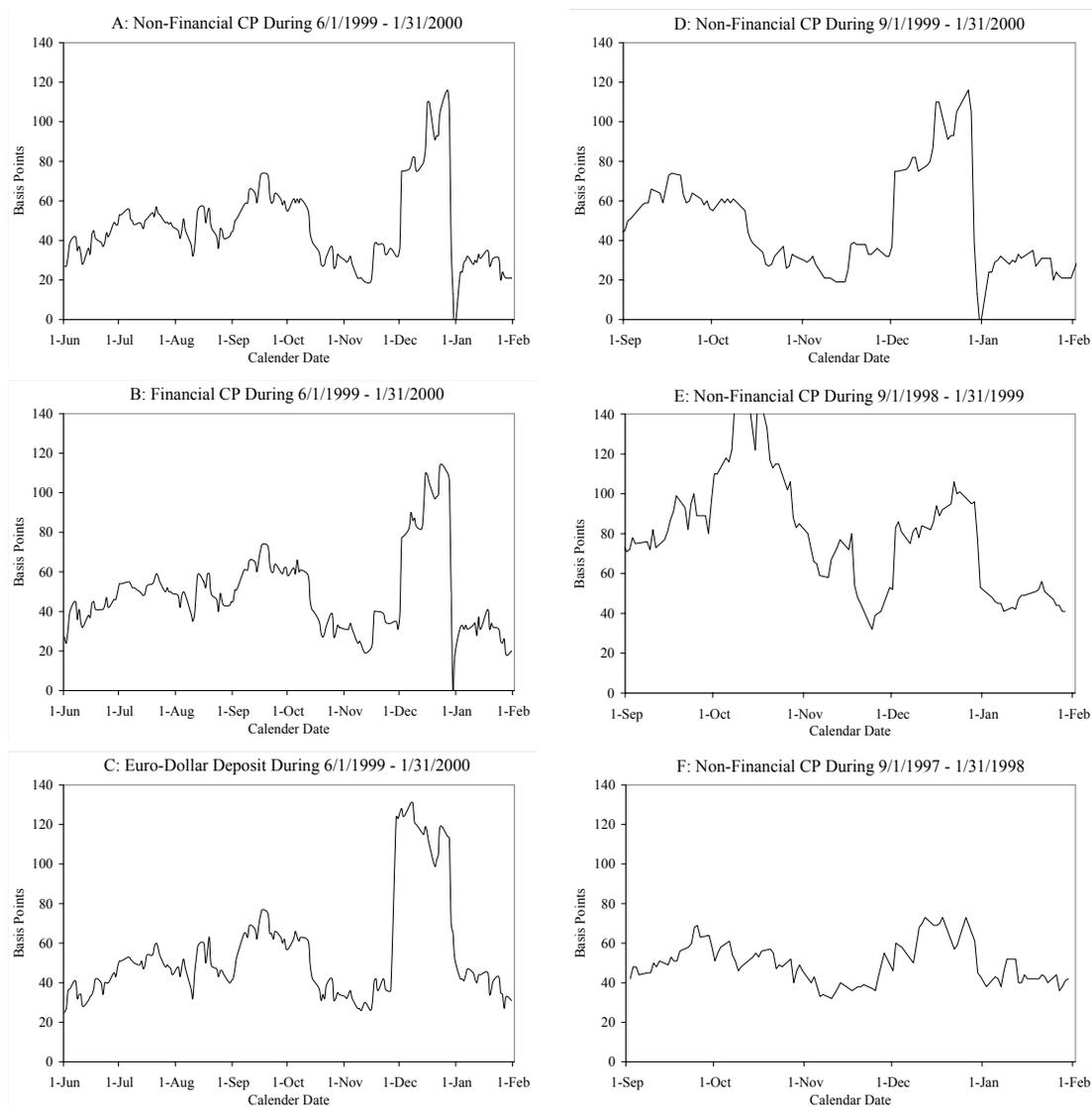


Figure 3: The Annual Cycle of the OTR-OFB Spread

This figure compares the OFB-OTR spread during 1999 and its corresponding historical average over the past 14 years (1983–1998). The spread during 1999 is referred to as the 1999 cycle and plotted as a solid curve. The historical average over the past 14 years is referred to as the past cycle and plotted as a dashed curve. The table in the graph reports the means and correlations of the two cycles during the first half, second half, and whole year. (Source of data: Lehman Brothers.)

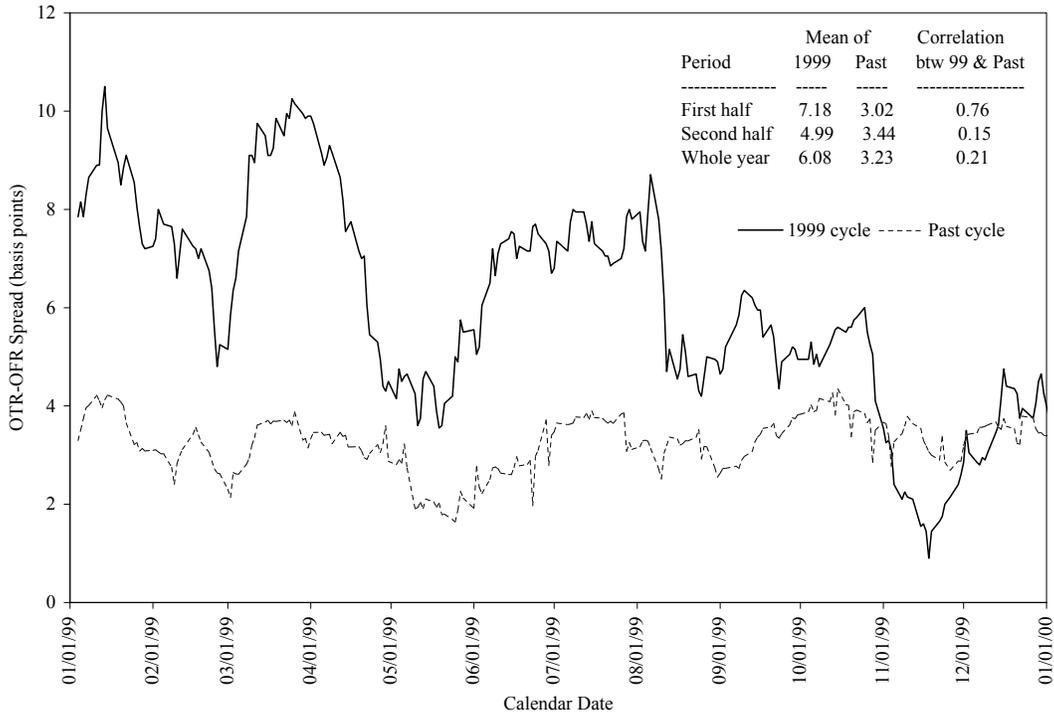


Figure 4: The Demand Curves in the Auctions of Y2K Options

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 that indicates the price (stop-out rate). (Source of data: Federal Reserve Bank of New York)

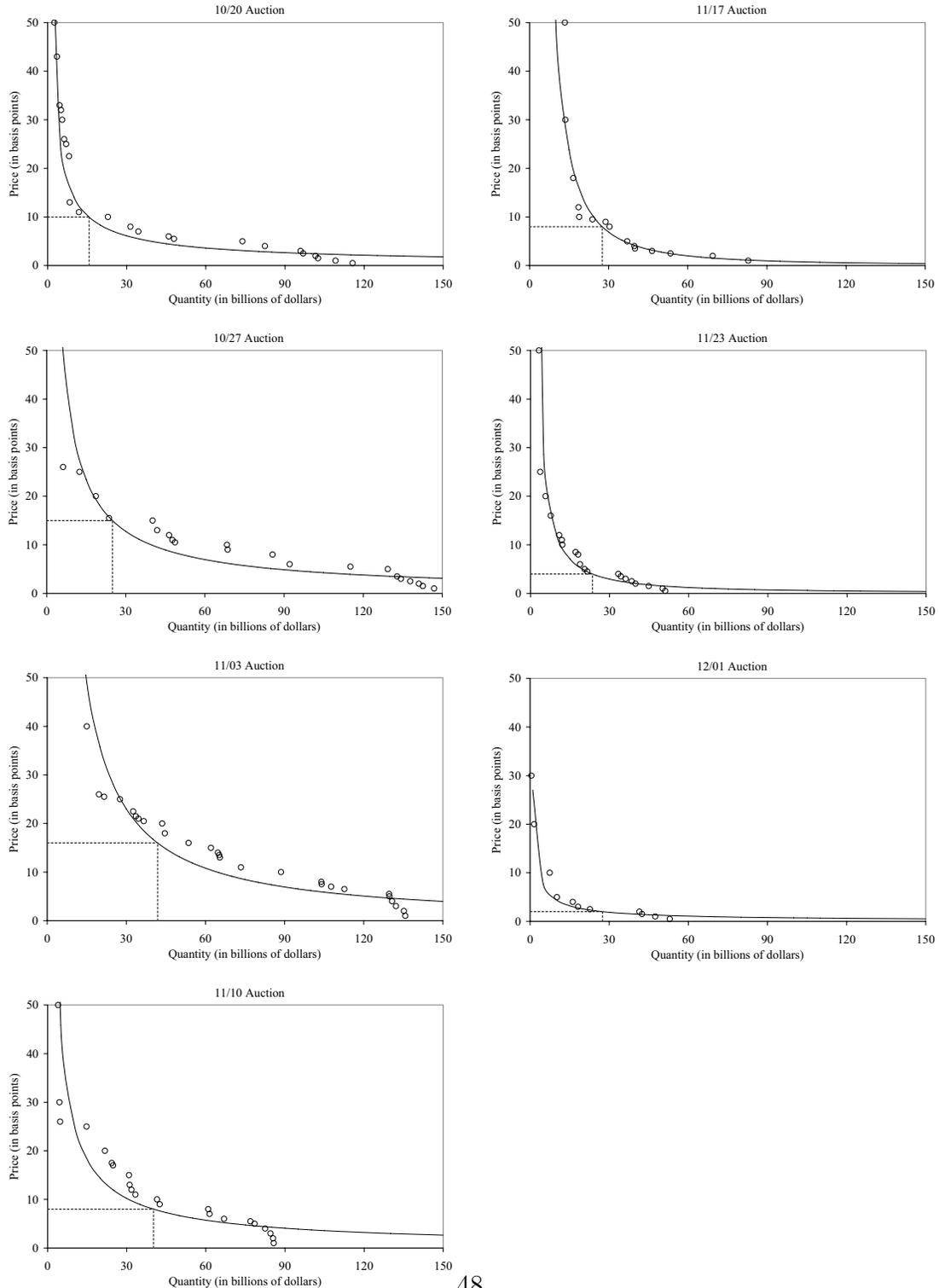


Figure 5: The OTR-OFB Spread and the Fed Actions

This figure links the OTR-OFB spreads to the Fed actions. The plots of the OTR-OFB spreads are exactly the same as in Figure 3 except that the period extends one month beyond the end of 1999. The shade indicates the period of Fed's issuance of Y2K options and the circles are the stop-out rates of the auctions of December 30 strip. (Source of data: Lehman Brothers and the Federal Reserve Bank of New York)

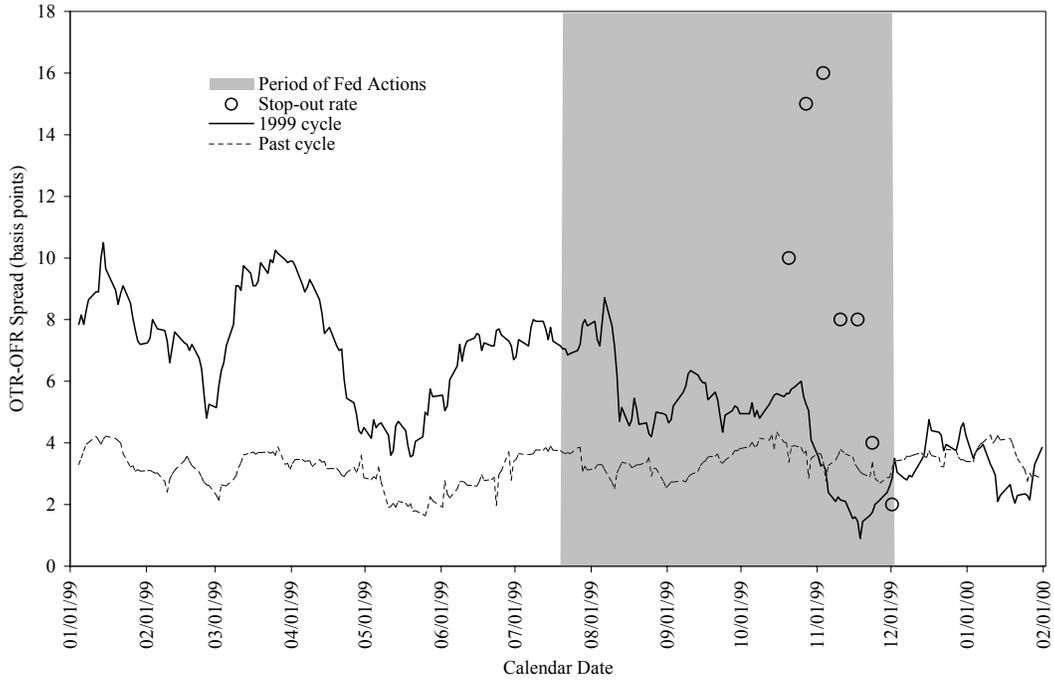


Figure 6: Reduction of the OTR-OFR Spread and the Demand of Y2K Options

This figure relates the reduction of OTR-OFR spread to the demand of Y2K options. Panel A plots the reduction of the OTR-OFR spread on each auction date along with the aggressiveness of the demand for Y2K options in the auction. Panel B plots the reduction of the OTR-OFR spread on each auction date along with the stop-out rates in the auction. The reduction of the OTR-OFR spread on the auction dates are the estimated $-\alpha_i$ for $i = 2, \dots, 8$ in Table 6. The numbers reported in the graphs are the correlations of $-\alpha_i$ s with either the aggressiveness of the demand curves (Panel A) or the stop-out rates in the auctions (Panel B).

