Y2K fears and safe haven trading of the U.S. dollar

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Abstract

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1. Introduction

> "Year 2000 is a unique problem that has various dimensions. It started as a technical problem, has progressed to being a senior management business issue and is now becoming a public confidence concern. In addition, it is unique in that we all know that the century date change will occur, but what will occur on that date is still open to differing perspectives. This is certainly a case in which the future is opaque." [Remarks by Federal Reserve Governor Roger W. Ferguson, Jr. at the Second Global Y2K National Coordinators Conference at the UN, June 22, 1999.]

The importance of *safe haven* currencies has been discussed extensively in academic and practitioner circles. The belief is that currencies such as the U.S. dollar and the Swiss Franc are ideal venues for investors to park their money during periods of uncertainty, and that investors from all over the world purchase assets denominated in these currencies when uncertainty increases. For instance, Cumby (1988) and Froot and Thaler (1990) suggest that the excess returns to the U.S. dollar beginning in the early 1980s were driven by purchases on the part of foreign investors who viewed the dollar as a safe haven. In this paper we investigate the extent to which safe haven flows affect liquidity in the foreign exchange market by considering a specific event—the Y2K problem.[1]

We use Y2K, rather than any of the other recent episodes believed to have been associated with safe haven flows[2], for several reasons. First, even though Y2K did not turn out to be a serious problem *ex post*, there is substantial evidence, exemplified by the Ferguson quote at the head of the paper, that it was perceived as a major problem *ex ante*. Second, and more

[1] The Y2K problem arose because dates were stored in computers using a DD/MM/YY format. It was believed that this format would lead computer systems to mistake January 1, 2000 for the year 1900, and thereby wreak havoc with date calculations. The only solution was to check and correct every date-relevant piece of computer code.

[2] The Mexican 'tequila' crisis in December 1994, the Asian 'flu' following the devaluation of the Thai baht in 1997, the Russian debt crisis in 1998, and the Brazilian crisis in 1999 are notable examples.

important, the event was clearly delineated—investors knew exactly when, if at all, the problem would appear (midnight on December 31, 1999), and when uncertainty would be resolved (early January, 2000). By contrast, none of the other candidate events was entirely predictable, so it is difficult to tell when safe haven flows associated with these events would have begun and ended. Third, analysis of financial market effects related to Y2K concerns is interesting in its own right, since there were fears that the Y2K problem would cause a meltdown in global financial markets. Finally, the U.S. was viewed as the best prepared to handle potential Y2K problems. As a result, the U.S. dollar became the principal safe haven currency as Y2K concerns grew.[3] Using the U.S. dollar to study safe haven flows around Y2K therefore represents our best chance of uncovering and understanding the effects of safe haven flows on financial markets.

Unfortunately, we cannot directly observe flows into the U.S. dollar because order flow data from the foreign exchange market are proprietary. However, we *can* draw inferences about these flows by examining the bid-ask spread in the foreign exchange market. Microstructure models of dealer behavior suggest that dealers manipulate their quotes and spreads to optimally manage their inventory positions given customer order flow and other information related to market conditions. In particular, dealers widen their spreads in response to increases in either the imbalance between supply and demand or uncertainty regarding the value of the asset. Consequently, quoted spreads have been used as a proxy for the underlying liquidity and order flow in financial markets (for evidence from the foreign exchange market see, for instance, Huang and Masulis, 1999, and for a survey, Dacrogna, Gencay, Mueller, Olsen and Pictet, 2001).

[3] For instance, "Experts testifying before the (U.S. Senate) Subcommittee and Special Committee (on the Year 2000 Technology Problem) consistently have stressed that while there is much uncertainty about Year 2000 readiness around the world, one fact is clear—most foreign countries lag behind the U.S. in their conversion activities" (page 90 of *Investigating the Impact of the Year 2000 Problem*, Report of the Senate Special Committee on the Year 2000 Technology Problem). Similarly, on October 13, 1999 Reuters reported that the U.S. intelligence community had a similar view of Y2K, "The United States is likely to emerge as a perceived safe haven for investors fleeing Year 2000 technology problems."

In the spirit of these studies, we investigate safe haven flow effects around Y2K by assuming that observed time-variations in the bid-ask spread are the result of changes in investor demand and market conditions. Specifically, we compare spreads as December 1999 was coming to an end and in January 2000, soon after the resolution of Y2K-related uncertainty, with spreads at other times. We expect to see safe haven flows into the U.S. dollar before January 1, 2000 and outflows after January 1, 2000 as investors repatriate their funds. These safe haven flows, if large, will result in the quoted spread being wider both before and after Y2K than at other times, as dealers attempt to optimally manage their inventory. Similarly, we expect to see safe haven driven supply and demand imbalances for forward contracts that expire after January 1, 2000 and thus wider spreads for these contracts.

There are, however, other potential explanations for a widening of the spread around Y2K. One possibility is that wide spreads are driven by a seasonal decrease in liquidity (e.g. end-of-year effects) or by changes in financial market conditions that are unrelated to Y2K (e.g. changes in monetary and fiscal policy). A second possibility is that a risk premium is embedded in quoted spreads around Y2K. For example, dealers quote wide spreads because they are concerned about holding inventory prior to Y2K rather than as a response to Y2K-related order flow. Our tests are designed to allow us to discriminate among these explanations.

Our analysis focuses on intraday data from the spot and forward markets for the Euro-U.S. dollar currency pair over the 13-month period, December 1, 1999 through December 31, 2000. As the most active, liquid currency pair in 2000 (BIS, 2002), the Euro-U.S. dollar currency pair is the least susceptible to problems related to thin trading and stale quotes. Analysis of both the spot and forward foreign exchange markets offers several advantages. First, the markets are based on the same underlying asset, so joint estimation of the effects across markets increases the power of our tests. Also, while both markets should be subject to safe haven flows, short-term traders are more likely to focus on the spot market and to concentrate their trades around January

1, 2000, while traders with longer horizons are more likely to trade in the forward market and to take on and unwind positions more gradually. The resulting differences in the spread patterns across the spot and forward markets can help separate safe haven flow effects from other potential explanations.

To isolate the impact of Y2K, we estimate a simple model for the intraday bid-ask spread in which we control for well-documented seasonalities and other factors likely to influence quoted spreads, including quoting frequency, the level of the exchange rate and exchange rate volatility. After controlling for these factors we find clear evidence of wider spreads in the spot and forward markets in December 1999 and January 2000. The spread in both markets widens as we approach the end of 1999 and continues to widen after January 1, 2000, the forward spread more weakly than the spot spread. The spot spread and the forward spread falls after the middle of January and is significantly below its level around Y2K between February and the end of the year.

To investigate the robustness of these results as well as to differentiate between safe haven effects and other explanations, we analyze daily spreads for the same spot and forward contracts used in the intraday sample over a longer period, June 1, 1999 through December 31, 2003. This examination confirms that the spreads in December 1999 and January 2000 are abnormally wide in a sample that includes episodes of Euro appreciation and depreciation versus the U.S. dollar and diverse macroeconomic conditions (economic expansion and contraction and different interest rate regimes). In addition, we find that the three-month forward spread starts to widen at the end of September 1999, around the time the three-month contract matures in January 2000, and widens further in November and December 1999 as Y2K approaches. Further analysis reveals an increase in the spread for one-month and six-month forwards during December 1999 and July 1999, roughly the first month the traded contracts expire in January 2000.

Interpreting our results, the fact that spreads do not widen in other Decembers and Januaries rules out a calendar explanation for the wide spreads around Y2K. Additionally, the fact that the spot and forward spreads remain wide through the end of January 2000, even though uncertainty regarding Y2K effects was resolved on January 1, 2000, suggests that the wide spreads around Y2K are not driven by a risk premium related to Y2K. Lastly, the initial widening of forward spreads in different months, when the contract in question matures in January 2000, is inconsistent with the wide spreads around Y2K being associated with one or more unobserved events in December 1999 and January 2000, such as a global shrinkage in liquidity or changes in U.S./European monetary policy.

The results from our analysis are, however, consistent with the effects of safe haven flows around Y2K. Safe haven flows into U.S. dollar assets create excess demand for the dollar before January 1, 2000, imposing inventory risk on foreign exchange dealers and causing them to widen their spreads. Likewise, the repatriation of funds following the resolution of Y2K-related uncertainty imposes inventory risk on dealers and is responsible for the wide spot spread in January 2000. Since investors are less likely to use the forward market to repatriate funds, imbalances are less severe in the forward market after Y2K and the forward spread is not as wide in January 2000. Order flow is more balanced after the end of January and this explains the stabilization of the spread. In sum, therefore, we document large spread adjustments in the foreign exchange markets associated with Y2K, and these adjustments suggest that safe haven flows can significantly impact foreign exchange market liquidity.

The rest of the paper is organized as follows. The next section describes our data. Section 3 presents our results and the final section concludes.

2. Data

We focus on intraday data from the Euro-U.S. dollar spot and forward markets. The intraday data consist of spot and three-month forward indicative quotes covering the 13-month period, December 1, 1999 through December 31, 2000, and are provided by Olsen and Associates. One of the advantages in using intraday data is that such data permit a detailed examination of spreads over the course of the 24-hour trading day. This time period is selected because it allows us to study spreads around the end of December 1999, which should be directly related to Y2K effects, and compare the results to a complete year of data to correct for seasonalities and other factors that influence quoted spreads.

We choose the Euro because it is the most liquid non-U.S. dollar currency, with approximately 40% of all foreign exchange transactions in April 2001 involving the Euro (BIS, 2002)[4]. We consider the forward market in addition to the spot market because outright forwards have become an important part of the foreign exchange market, with the volume of traded forward contracts being approximately one-third that of spot contracts and growing (Flood, 1991; BIS, 2002). The three-month forward contract is the most liquid forward contract. To our knowledge, ours is one of the first studies to exploit the extra information on the nature of supply and demand in the foreign exchange market contained in data from the forward market.

The forward data consist of time-stamped *forward points* as quoted by Reuters and compiled by Olsen and Associates. To obtain the forward quotes from the forward points we sort the datasets containing the spot quotes and the forward points by time stamp and then follow the standard forward quoting convention. In other words, if the forward points are ascending, the forward bid (ask) quote is calculated as the sum of the most recent spot bid (ask) quote and the

[4] This 40% market share for the Euro compares to market shares of 90% for the U.S. dollar, 24% for the Japanese Yen and 14% for the Pound Sterling. The shares of other currencies are less than 10%. Since each foreign exchange transaction involves two currencies, the proportional contribution of all currencies sums to 200%.

forward bid (ask) point; if the points are descending, the forward quotes are obtained by subtracting the forward points from the spot quotes.

Although the data consist of spot and forward indicative quotes, there is abundant evidence that indicative quotes provide significant insights into the actual transaction (or "firm") data that we would ideally use. Goodhart, Ito and Payne (1996) and Danielsson and Payne (2002), for example, have considered the quality of indicative quotes as a proxy for transaction data. They find that at coarser frequencies (i.e. when the measurement interval is greater than 10 minutes in length) the indicative quote and transaction data yield similar results. In view of this correspondence, our analysis is based on 15-minute measurement intervals. We use 15-minute intervals to be consistent with previous intraday studies of foreign exchange spreads, such as Huang and Masulis (1999). We also consider 60-minute measurement intervals and reach identical conclusions.

To measure market liquidity, we could use the quoted spread or the relative spread, defined as the quoted spread scaled by the quote midpoint. The former has been used in Bollerslev and Melvin (1994), Hartmann (1999) and Huang and Masulis (1999), for example, while the latter has been used in Hau, Killeen and Moore (2002), for instance. We examine the quoted spread, for the following reasons. Bid and ask prices in the Euro-U.S. dollar market are set to four decimal places, and spreads are quoted in multiples of 0.0001 (one pip). Bessembinder (1994) and Bollerslev and Melvin (1994), among others, have documented that foreign exchange dealers concentrate their quoted spreads on certain values (e.g. 5, 7 or 10 pips). This granularity tends to make the quoted spread stable, so changes in the quoted spread are more likely to occur in response to significant changes in market conditions such as order flow related inventory effects[5]. By contrast, the relative spread will change as a result of a change not only in the quoted spread but also in the quote midpoint. Given our interest in the effects of order flow on liquidity,

[5] For recent discussions of the granularity in foreign exchange spreads and its relation to dealer inventory management, market conditions and transaction costs, see Goodhart, Love, Payne and Rimes (2002), Lyons (2002a) and Rogoff (2002). For a theoretical discussion, see Hasbrouck (1999, 2000).

we believe the quoted spread is the more appropriate liquidity measure. Although we analyze the quoted spread, our tests control for the possible influence of changes in the level of the exchange rate on the spread.[6]

Our time series tests require equally spaced observations and, since quotes arrive irregularly, we use the median spread in each 15-minute interval. Using the median allows us to capture the characteristics of all the quoted spreads during the interval, while mitigating the influence of outliers. When we repeat our tests using the mean spread or the final spread quoted in a given interval our results are similar, so we only present the results based on the median spread. As in other studies (starting with Bollerslev and Domowitz, 1993), we exclude data corresponding to the weekend, which is defined as extending from 20:00 GMT Friday evening (the close of the North American markets) until 24:00 GMT Sunday evening (when trading commences in the Far East). The rationale is that, due to low trading volumes, quoted spreads over the weekend are much larger than at other times and are not typical of the market conditions we are interested in studying.

We supplement the intraday data with daily data from the spot and three-month forward markets over a longer time period, June 1, 1999 through December 31, 2003.[7] Daily bid-ask spreads for the Euro-U.S. dollar spot and three-month forward contracts are obtained from DataStream and represent the closing values in London from WM/Reuters.

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[6] Since the spreads for indicative quotes are stable in comparison to firm transaction data, our use of indicative spreads should, if anything, lead to a bias against finding safe haven trading effects. Some other characteristics of indicative quotes relevant to our analysis are as follows: quoted indicative spreads are wider than traded spreads (they include a safety margin so dealers can make fine changes in the bid and ask prices based on market conditions); dealers often choose one of the prices to attract investors and make the other price unattractive (quote shading); indicative quote spreads are larger when trading and quoting activity are low (e.g. over the weekend); and more actively traded currencies have tighter spreads (for more detail see Dacrogna et al., 2001).

[7] We start on June 1, 1999 rather than January 1, 1999 (the day the Euro officially started trading) in order to avoid possible new currency trading effects associated with the Euro while still studying the markets before Y2K.

3. Results

Our first look at the data takes the form of a graphical analysis of the spread around Y2K. We then carry out regression tests to formally confirm the findings from this analysis and evaluate alternative explanations.

3.1. Y2K effects: Graphical analysis

We graph the intraday spread in the spot and forward foreign exchange markets in figures 1 and 2. Figure 1 provides the median Euro-U.S. dollar spot spread for each 60-minute interval over the 13-month sample period, December 1999 through December 2000 (we do not present the 15-minute spread series because the larger number of observations makes the figure too dense to see any patterns). The solid line is a weekly moving average, which helps interpretation by compensating for intraday and daily seasonalities. One can see that the median spread averages about 5.1 pips ($0.00051) in early December 1999, and it increases in the third week of December to roughly 6.2 pips, where it remains until mid-January 2000. The spread declines during the latter part of January 2000, and by the end of February is approximately 3 pips, where it remains for the rest of the year. The fact that there is no visible increase in the spread around Christmas 2000 provides preliminary evidence that the wide spread in December 1999 is unusual.

Figure 2 provides the median 60-minute spread in the three-month forward market. Similar to figure 1, this figure suggests a change in liquidity around January 1, 2000. The quoted forward spread is almost 5.75 pips in early December 1999, but increases rapidly to over 7 pips by the end of December. The spread starts to decrease immediately after January 1, 2000 but only returns to its levels of early December 1999 at the end of January. As in the spot market, the forward spread is remarkably stable for the rest of the year, at approximately 5.4 pips.

Figure 3 provides histograms of the cumulative distribution of the spot and forward spread during the period around Y2K, defined as December 1999 and January 2000, and during the 11-month non-Y2K period, February 2000 through December 2000. The histograms are

constructed using all of the median 15-minute spreads in the two periods. Figure 3 reveals a perceptible rightward shift in the distribution of the spread in the period around Y2K. For instance, figure 3a shows that 12 percent of all spot spreads exceed 5 pips during the non-Y2K period whereas the proportion rises to 21 percent around Y2K. The forward spread distribution, presented in figure 3b, also shifts rightward around Y2K. Nine percent of all forward spreads during the non-Y2K period exceed 7 pips compared to 22 percent around Y2K. A non-parametric rank sum test shows that the rightward shift in the spot and forward distributions around Y2K is statistically significant (p-values less than 0.0001 in each case). The means and medians of the spread distributions for the non-Y2K and Y2K periods are also significantly different. For instance, the spot mean increases from 4.6 pips to 5.5 pips and the forward mean from 5.4 pips to 6.2 pips.[8]

Figures 1 through 3 show that the spread in both the spot and forward foreign exchange markets widens significantly immediately before January 1, 2000 and narrows by the end of January. The observed widening of the spread in late December 1999 is consistent with excess demand for the U.S. dollar, its continued elevation in early January 2000 is consistent with excess supply of the U.S. dollar, and the narrowing of the spread by the end of January 2000 is consistent with a return to more balanced order flow. Thus, the patterns in the spreads are consistent with the effects of safe haven inflows and outflows associated with Y2K, but we must control for factors that affect spreads and explore alternative explanations before we can reach more definite conclusions. This is the objective of the remainder of the paper.

[8] A more detailed month-by-month comparison (not presented) shows a rightward shift in the distribution of the spread in both December 1999 and January 2000 relative to every other month in the year 2000. Analysis of all spreads (rather than the median spread) yields identical conclusions.

3.2. Regression tests

3.2.1. Methods

We estimate a two-equation seemingly unrelated regression (SUR) model for the intraday bid-ask spread in the spot and forward markets over the thirteen-month sample period. A SUR framework enables us to exploit the contemporaneous correlation between the spot and forward spreads (the OLS residuals have a correlation of 0.28). The model uses dummy variables to capture seasonal components in the data and adds other factors found to influence quoted spreads:

$$y_t^s = \alpha_0^s + \alpha_1^s ddec_{1999,1} + \alpha_2^s djan_{2000,1} + \alpha_3^s djan_{2000,2} + \alpha_4^s ddec_{2000,1} + \alpha_5^s ddec_{2000,2} + \sum_{i=2}^{11} \beta_i^s dmth_{i,2000} + \sum_{j=1}^{4} \delta_j^s dgeog_j + \phi_s n_{s,t-1} + \gamma_s \sigma_{s,t-1} + \sum_{k=2}^{3} \theta_k^s dsptlev_k + \varepsilon_t^s \quad (1a)$$

$$y_t^f = \alpha_0^f + \alpha_1^f ddec_{1999,1} + \alpha_2^f djan_{2000,1} + \alpha_3^f djan_{2000,2} + \alpha_4^f ddec_{2000,1} + \alpha_5^f ddec_{2000,2} + \sum_{i=2}^{11} \beta_i^f dmth_{i,2000} + \sum_{j=1}^{4} \delta_j^f dgeog_j + \phi_f n_{f,t-1} + \gamma_f \sigma_{f,t-1} + \sum_{k=2}^{3} \theta_k^f dfwdlev_k + \varepsilon_t^f \quad (1b)$$

In specification (1):

- y_t^s and y_t^f are the median spread in the spot and forward markets in 15-minute interval *t*.
- $ddec_{1999,1}$, $djan_{2000,1}$, $djan_{2000,2}$, $ddec_{2000,1}$ and $ddec_{2000,2}$ are dummy variables corresponding to the first half of December 1999 (December 1 through 15, inclusive), and the first and second halves of January 2000 and December 2000, respectively.
- $dmth_{2000,i}$ are month dummies corresponding to the rest of the year 2000 (*i* = 2 for February, 3 for March, … and 11 for November).
- $dgeog_j$ are dummies to account for the well-documented differences in the spread as trading moves from the Asian markets to the European and then the North American markets over the 24-hour trading day (e.g. see Bollerslev and Domowitz, 1993; Andersen

and Bollerslev, 1997; and Huang and Masulis, 1999). $dgeog_1$ corresponds to Asian trading (00:00-08:00 GMT), $dgeog_2$ to European trading (08:00-12:00), $dgeog_3$ to the overlap in European and U.S. trading (12:00-16:00) and $dgeog_4$ to post-U.S. trading (20:00-24:00).[9]

The last three regressors, quoting frequency, exchange rate volatility, and dummy variables for the level of the exchange rate are control variables. Many studies show that the bid-ask spread is related to both quoting frequency and volatility (see, for instance, Dacrogna et al., 2001; Sarno and Taylor, 2001; and Lyons, 2002b).

- Quoting frequency ($n_{s,t-1}$ and $n_{f,t-1}$) is the number of quotes issued during the prior 15-minute interval. Quoting frequency is a measure of dealer competition, and an increase in quoting frequency should lead to a decrease in the spread (e.g. Huang and Masulis, 1999).[10] We relate the spread in interval *t* to quoting frequency in interval *t-1* to avoid potential simultaneity problems.
- Realized volatility in the spot and forward markets ($\sigma_{s,t-1}$ and $\sigma_{f,t-1}$) is computed as the sum of the squared demeaned 15-minute returns over the previous 96 intervals (starting with interval *t-1*), equivalent to one day (see Andersen, Bollerslev, Diebold and Labys, 2001). We include realized volatility to capture exchange rate uncertainty, since the spread should increase as uncertainty increases (see, for example, Bessembinder, 1994; and Bollerslev and Melvin, 1994). Our use of one day of squared returns has the added advantage of accounting for intraday seasonalities in volatility.

[9] Little work has been done to characterize seasonalities in the forward market. We assume that these seasonalities are similar to those in the spot market. We also estimate a version of this model adding dummies for the different days of the week. This model is not presented, as there is little variation in the spread across days. Our approach is consistent with existing research, which ignores variations across working days.

[10] Quoting frequency can also be thought of as a proxy for trading volume. We do not rely on this interpretation because the quality of quoting frequency as a proxy for trading volume appears to have deteriorated in the case of the Euro (see, for instance, Hau, Killeen and Moore, 2002, and Killeen, 2003).

- Lastly, we include two dummy variables, $dsptlev_k$ and $dfwdlev_k$ (k = 2, 3), to capture the possible effects on the spread of variations in the level of the spot and forward rates. We cannot include the spot or forward rate itself as a regressor, because each is a non-stationary random variable. Hence, we resort to the use of dummy variables. $dsptlev_2$ ($dsptlev_3$) takes a value of one when the spot rate is greater than the cutoff for the middle (top) one-third (33%) of the spot rate distribution and is zero otherwise, and analogously for $dfwdlev_2$ and $dfwdlev_3$. If the spot spread increases as the level of the spot exchange rate increases the coefficient on $dsptlev_2$ and the sum of the coefficients on $dsptlev_2$ and $dsptlev_3$ should be positive, and similarly for $dfwdlev_k$.

In this specification, we are especially interested in the estimated values of α_0 to α_3, which represent Y2K effects in the spot or forward market (we suppress superscripts to simplify the discussion). Given our definitions of the other dummy variables, the intercept, α_0, represents the mean 15-minute spread during U.S. trading (16:00-20:00 GMT) in the second half of December 1999.[11] This becomes our benchmark. The coefficient on a particular dummy variable reflects the difference between the mean effect during the period to which the dummy corresponds and the mean during U.S. trading in the latter half of December 1999 (our benchmark), holding all else constant. For instance, α_1 is the difference between mean spreads during U.S. trading in the first half of December 1999 and our benchmark period, *ceteris paribus*. Similarly, α_2 and α_3 are the differences corresponding to U.S. trading in the first and second halves of January 2000. As a final illustration, the difference between mean spreads during Asian trading in the second half of December 1999 and U.S. trading over the same period is δ_1, and the difference between mean spreads during European-only trading in October 2000 and U.S. trading in the second half of December 1999 is $\beta_{10} + \delta_2$.

[11] The correct way to interpret our results is in terms of the mean of the median spread during a 15-minute interval. However, for the sake of brevity, we talk in terms of the mean spread.

Diagnostic tests indicate that the SUR residuals are heteroscedastic and autocorrelated, so we estimate (1a) and (1b) by Hansen's Generalized Method of Moments (GMM) using the independent variables for each equation as the instruments for that equation. This system is just-identified and the coefficient estimates are the same as the SUR estimates, but GMM delivers a heteroscedasticity and autocorrelation consistent covariance matrix for these estimates.

To formally investigate several hypotheses regarding changes in spreads around Y2K, we test parameter restrictions of the form $R\beta = 0$, where β is the $N\times1$ parameter vector from (1) and R is a $K\times N$ matrix embodying K simultaneous parameter restrictions. Letting Ω be the GMM covariance matrix of the parameters, each hypothesis is tested by forming the Wald statistic, $Z = (R\hat{\beta})'(R\Omega R')^{-1}(R\hat{\beta})$, where $\hat{\beta}$ is the estimated parameter vector. Z is distributed $\chi^2(K)$ (for example, Greene, 1993). Table 2 presents a subset of results from these tests, which we discuss below.

3.2.2. Estimates

Table 1 presents the coefficient estimates for the complete SUR model for the spot and forward spreads. We start with the results for the spot market and the calendar dummies. Only the coefficient on the dummy for the first half of January 2000 is significantly above zero (with a heteroscedasticity and autocorrelation consistent t-statistic of 3.24). The coefficients on the remaining calendar dummy variables are negative (with t-statistics of -3.27 for the second half of January 2000 and less than -10 for virtually every other month). Thus, the mean spread in the first half of January 2000 is larger than the next largest mean spread, that in the second half of December 1999 (which is reflected in the intercept). The spread during the second half of January 2000 is significantly tighter than the spread immediately around January 1, 2000 but is still wider than the spread in every other month in 2000 (p-values from Wald tests of pairwise comparisons of the coefficients, shown in table 2, are all less than 0.0001). These results are

consistent with the graphical findings from figure 1. The fact that the spread is significantly tighter in the second half of December 2000 than in the corresponding period in December 1999 indicates that the latter is not driven by a December seasonal.

To shed light on the economic significance of the effects, we also consider the size of the estimated coefficients. The coefficients suggest that, *ceteris paribus*, the mean spot spread at the end of December 1999 is wider by almost 0.75 pips than the mean spread during the first half of December 1999, and the spread during the first half of January 2000 is 0.3 pips wider than at the end of December 1999. The spread is tightest from February to August 2000, approximately one pip below the spread at the end of December 1999, and widens gradually over the rest of the year.[12] Despite this increase, the spread during the latter part of December 2000 remains more than half a pip tighter than during the same period in December 1999. Since the mean spread at the end of December 1999 (the intercept) is 5.3 pips, our analysis suggests that the spread is a minimum of 10% wider in late December 1999 and early January 2000 than in every other month. It should be noted that these results do *not* imply that the spread is wider during every period in December 1999 than during every period in 2000. For instance, the differences in the coefficients on the geographic region dummy variables (summarized below) are such that the mean spread is tighter during U.S. trading in December 1999 than during Asian trading in November 2000. However, controlling for region and other influences on the quoted spread, the results imply that the spread is widest in late December 1999 and early January 2000.

The coefficients on the geographic dummies show that the mean spread during Asian trading is more than 0.80 pips wider than the spread during North American trading (our baseline period). The spread tightens slightly as European trading commences, is tightest when both

[12] The widening of the spread toward the end of the year can be attributed, at least in part, to European, Japanese and U.S. central bank intervention to support the Euro between September and early November 2000. Bossaerts and Hillion (1991) and Naranjo and Nimalendran (2000) model and present empirical evidence of currency spreads widening during periods of central bank intervention.

European and North American markets are open and is widest when none of these markets are open.

The final coefficients to consider are those on the control variables. The number of spot market quotes in the prior 15-minute interval is an important control given the possibility of differences in dealers' quoting behavior around Y2K. Consistent with the interpretation of quoting frequency as a measure of competition, the estimated coefficient on the number of quotes is significantly negative (t-statistic = -35). We also control for realized volatility, measured by cumulative intraday volatility over the preceding trading day. There is some evidence that the spread increases following a period of increased spot market volatility (though the t-statistic on the coefficient is only 1.6). The dummy variables for the level of the spot rate allow us to investigate the relationship between the spread and the value of the Euro. The coefficients are positive (implying that the spread increases as the exchange rate increases), though only the coefficient on $dsptlev_3$ (representing values in the top one-third of the spot rate distribution) is significantly different from zero (here, too, the t-statistic of 1.8 is marginal).[13]

Because the results for the 15-minute forward spread are similar to those for the spot spread, we only briefly discuss these results. As in the spot market, the forward spread widens through December 1999 and early January 2000, but starts to decrease in the second half of January and remains relatively constant for the rest of the year. Thus, after controlling for other factors influencing the forward spread we find that it, too, is widest in the period surrounding January 1, 2000. The differences between Y2K and the rest of the sample period are, however, not as striking as in the spot market. Notably, although the coefficient on the dummy variable for the first half of January is still positive, it is only marginally significant (t-statistic = 1.5) and is one-half as large as that in the spot market.

[13] For robustness, we have re-estimated the model using alternative exchange rate categories (quintiles and deciles, for instance). Our conclusions are similar, and we only report this parsimonious specification.

Similar to the spot market, the coefficients on the geographic dummies imply that the spread is largest during Asian trading and smallest during the overlap between European and North American trading. In contrast to the spot market, the forward spread is tighter when the European markets are open on their own than when only the North American markets are. The forward spread is negatively related to the number of forward market quotes, as in the spot market, but is more strongly related to realized volatility and the level of the exchange rate (the coefficients on the two exchange rate dummies are reliably positive).

We investigate the robustness of our findings both by considering sub-periods and by estimating restricted versions of the model. To investigate the possibility of period-specific influences on our results, we estimate the model across various sub-periods. Since the pattern in the calendar dummies suggests a widening of the spread after August 2000, we estimate the model using data for December 1999 and January 2000 matched separately with data for February-August 2000 and for September-December 2000. Similarly, we combine data for December 1999 and January 2000 with data for sub-periods of equal length, February-June 2000 and July-December 2000. We also estimate the model over the period December 1999 through March 2000, since the Euro-U.S. dollar spot rate is relatively stable during this period, as well as over other groupings, not necessarily consecutive, but with similar exchange rates. In every sub-sample, the spread in the spot and forward markets is widest around Y2K. To confirm that the results are not sensitive to our choice of control variables, we re-estimate model (1) after excluding combinations of the control factors. While this changes the coefficients on the geographic dummy variables somewhat, it does not materially alter the coefficients on the calendar dummies or our conclusions regarding the width of the spread around Y2K.

We use the Wald test to compare the coefficient estimates across or within markets, and table 2 summarizes some of the results of interest. Panel A presents the results of cross-equation tests. There are interesting patterns in the coefficients on the calendar dummies. We cannot reject the hypothesis that the coefficients on the calendar dummies in the spot and forward

markets are equal for the period around Y2K, but we are able to reject this hypothesis for the other months regardless of how they are grouped. This pattern in the spot and forward coefficients is consistent with the safe haven flows explanation. Safe haven flows would have been most intense around Y2K and it is logical that the spread in the spot and forward markets is similarly affected during this period. At other times in the year, there are fewer common order flow shocks in the two markets and this delinks the spot and forward markets to a greater degree.

The coefficients on quoting frequency, volatility and the exchange rate dummies are larger in the forward market than the spot market. The greater sensitivity of the forward spread to these variables suggests that liquidity is lower in the forward market than the spot market, and is not surprising given the large differences in the volume of spot and forward activity (BIS, 2002) and in quoting frequency. For example, the median daily quoting frequency is about 11,000 quotes in the spot market and 400 in the forward market. The larger intercept for the forward market than the spot market is also consistent with lower forward market liquidity.

Panel B of table 2 summarizes the results of Wald tests of the equality of coefficients within the spot and forward markets. A joint test shows that the coefficients on the non-Y2K month dummies are significantly different from each other in the spot and forward markets, as are the Y2K dummies.[14] More importantly, the coefficients on the Y2K dummies, individually and as a group, are significantly different from those on the non-Y2K monthly dummies. This joint test confirms that the spread around Y2K is unusually wide in both the spot market and the forward market.

We carry out one final set of robustness checks. Since the forward quotes are calculated by combining the prevailing spot quotes and the forward points, the width of the forward spread is affected by the width of the spot spread. We investigate whether the spread in the forward market widens independently of the spot spread around Y2K by re-estimating the SUR for the

[14] In contrast to the joint test, individual pair-wise tests frequently show that the non-Y2K dummies are no different from each other.

spot spread and the forward points-based spread. The results for the spot spread are similar to the original results, with the spread widening in December 1999 and narrowing after the end of January 2000. The forward points-based spread widens at the end of December 1999, and starts to narrow immediately after January 1, 2000, although it remains wider in January 2000 than in the other months of the year. The narrowing of the spread calculated from the forward points immediately after Y2K indicates that much of the wide overall forward spread in January 2000 is explained by the wide spot spread.

In summary, our investigation of 15-minute spot and forward spreads reveals that the spread in both markets is unusually wide preceding the Y2K changeover. The spread in both markets widens further until the middle of January, though the increase in the forward spread is smaller than, and is driven largely by, the increase in the spot spread. The fact that the spread is abnormally wide in both markets in late December and early January after controlling for quoting frequency, volatility and the level of the exchange rate suggests that changes in quoting behavior, uncertainty or the value of the Euro versus the U.S. dollar are not responsible for the wider spread around Y2K.

To interpret these results we use insights from market microstructure models of dealer behavior that focus on inventory holding costs. These models suggest that the cost to a dealer of holding inventory is based on the liquidity of the asset as well as uncertainty regarding its value (for a comprehensive discussion see O'Hara, 1995). Lyons (1995) and Yao (1998) test these models by investigating the quoting behavior of individual foreign exchange dealers and find that inventory considerations play a large role in the determination of quoted spreads.

A logical source of the wide spread before the end of the year is an increased demand for the U.S. dollar as a safe haven currency around Y2K. This increase in the demand for U.S. dollars results in dealers widening their spread to reduce the probability of unwanted inventory accumulation and as compensation for bearing inventory risk. An explanation for the wide spread after January 1 is inventory costs associated with dollar selling as investors reverse safe haven

flows. The fact that the spread widens further after January 1, 2000 indicates that post-Y2K flows out of the U.S. dollar are significant and are possibly more temporally concentrated than are safe haven flows into the U.S. dollar before Y2K.[15]

The more moderate increase in the forward spread after January 1, and the contribution of the spot spread to this increase, suggest that a major source of the post-Y2K forward market illiquidity is spot market illiquidity. The weaker evidence of safe haven flow effects in the forward market after Y2K is plausible since fewer investors will use new three-month forward contracts (in preference to spot transactions) to repatriate their U.S. dollar holdings or to reverse forward positions established before Y2K. For both reasons, order flow in three-month forwards should be more balanced than spot order flow after Y2K. Importantly, the large spot and forward spreads *after* the resolution of Y2K-related uncertainty suggest that the wide spreads around Y2K are driven principally by safe haven flows and not by a risk premium or liquidity premium associated with the event, which should have vanished immediately after January 1, 2000.[16]

3.3. Analysis of daily data

The results in the previous subsections show that the spot and forward foreign exchange spread is unusually wide around Y2K. In this section we briefly consider the robustness of this conclusion using daily data over a longer 55-month period, June 1, 1999 through December 31, 2003. This analysis is useful because it allows us to compare the spread around Y2K with the

[15] We look for evidence of shifts in the demand for U.S. dollar and Euro denominated assets around Y2K, and we find, after correcting for seasonalities, an increase in U.S. M1 (which includes demand and short-term deposits) in November 1999 and December 1999 and a decline in January and February 2000, with the reverse generally holding for the Euro-zone. Constructing a series of unexpected monthly flows into U.S. money market funds (as in Warther, 1995) we find a large inflow in December 1999 and a large outflow in January 2000. Stock fund flows, which provide a natural control, are flat. These findings, while informal, are consistent with overseas funds being invested in short-term and secure U.S. assets before Y2K and withdrawn afterwards.

[16] Indeed, Hartmann, Manna and Manzanares (2001) document higher yields on overnight bonds on December 31, 1999 which vanish after January 1, 2000. Longstaff (2004) finds that at times of market risk there is a premium in the yields on less liquid U.S. Treasury securities versus their more liquid counterparts. This, too, declines once uncertainty is resolved. If similar risk or liquidity premia are the source of the wide spreads we document, their effects should vanish shortly after the uncertainty was resolved (i.e. on January 1, 2000).

spread measured over periods of Euro appreciation and depreciation, varied economic conditions and different interest rate regimes. To save space, we only discuss the regression results.

Table 3 presents coefficient estimates from model (1a) and (1b) modified to apply to the daily spread in the spot and three-month forward markets. The daily spread specification does not include quoting frequency or the geographic dummies (these cannot be computed from daily data), but does include realized volatility, based on the sum of the squared demeaned returns over the previous 22 days (equivalent to one month), dummies for every month in the sample period and dummies for the levels of the spot and forward exchange rate, defined as in the intraday analysis.

The calendar dummies allow us to estimate the mean spread for each month in the sample period relative to our benchmark period (the latter part of December 1999) but, to conserve space, we do not present the 55 coefficients from this estimation. Instead, we report the t-statistics and coefficients for each month in the years 1999 and 2000 (which allow us to draw inferences about the width of the daily spread in the period around Y2K), as well as the *average* coefficient and t-statistic broken out by calendar month for the rest of the sample. Since the three coefficient estimates and t-statistics per month (e.g. for January in 2001, 2002 and 2003) are relatively stable, the monthly averages are very representative.

Overall, the daily results provide evidence consistent with safe haven trading effects. The average monthly coefficients for 2001-2003 are negative in each market, and the average t-statistics are, in most cases, larger than 2.0 in absolute value.[17] The spot spread starts to increase in November 1999, is widest at the end of December 1999, and remains wide throughout January 2000. It tightens thereafter and, for the rest of the sample period, is narrower than the spread in December 1999 and January 2000. Similar results hold for the daily three-month forward spread. The spread widens gradually, starting in late September 1999, and stays wide until February

[17] The coefficients on the dummies for each of the months in 2001-2003 are all negative and virtually all are significantly below zero at the 5 percent level or better. Thus, the average coefficients and t-statistics accurately describe the patterns in the individual months.

2000. Once again, the spread is significantly narrower during the remainder of the sample period. There is no evidence of an increase in the spot or forward spread during the other Decembers or Januaries in the sample.[18]

In results not presented, we also examine the spread on one-month and six-month forward contracts and find some evidence of the spread on the one-month (six-month) forward starting to widen in December 1999 (July 1999). This pattern is intriguing and consistent with our findings for the three-month forward contract, and suggests that the spread widens roughly during the first month in which the forward contract matures in January 2000, i.e. after Y2K. The fact that the spread widens *at different times* for contracts that share the feature of maturing in January 2000 is inconsistent with a single event being responsible for the wider spreads around Y2K. Rather, this evidence indicates that the decline in foreign exchange liquidity is driven by order imbalances related to Y2K.

4. Concluding comments

Academics and practitioners have, for years, discussed the effects of safe haven trading on prices in financial markets, yet we have little evidence regarding the economic importance of safe haven trading. This paper considers the issue by examining liquidity in the Euro-U.S. dollar spot and forward markets around the Y2K changeover. As a clearly defined episode of global uncertainty, widely believed to have resulted in safe haven trading of the U.S. dollar, this event allows a clean analysis of the impact of demand-supply imbalances on the spreads quoted by foreign exchange dealers.

A detailed examination of the quoted intraday spread in the spot and forward markets from December 1, 1999 to December 31, 2000 shows that the spread in the spot and forward

[18] To determine whether the coefficient estimates around Y2K are significantly different from those in other months, we carry out Wald tests of the equality of the coefficients on the calendar dummies in the Y2K-related months and the non-Y2K months (results not reported). The coefficients around Y2K are always significantly different from those in other months but the non-Y2K coefficients are often no different from one another.

markets widens before January 1, 2000, widens further in the first half of January 2000, and returns to normal levels after the end of January. The fact that this increase in the spread remains highly significant after we control for seasonalities and other determinants of the spread (the level of the exchange rate, quoting frequency and volatility) suggests that the wide spread around Y2K neither has a calendar explanation nor is driven by changes in other market characteristics. The fact that the spread remains wide until the end of January 2000, well after the uncertainty associated with Y2K had been resolved, indicates that the wide spread is not just the result of a risk premium associated with Y2K. Finally, the fact that these effects are present in both the spot market and the forward market suggests that it is not an effect unique to any one market or any one type of investor.

The robustness of these results is confirmed when we examine the daily spread over a longer sample period, June 1, 1999 through December 31, 2003, which includes episodes of Euro appreciation and depreciation and varied economic conditions. The daily analysis also shows that the spread for forward contracts of differing maturities starts to widen at different times, during the month that the traded contract expires in January 2000, and suggests that a single event is not responsible for the wide spot and forward spread around Y2K.

Having excluded other explanations, we are left with one based on safe haven flows. In particular, safe haven flows into the U.S. dollar before Y2K cause dealers to quote wide spreads as they attempt to manage inventory risk. Spreads stay wide in January 2000 due to inventory risk associated with U.S. dollar outflows as investors repatriate funds. We conclude that safe haven flows can significantly impact financial market liquidity.

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Table 1. Intraday regression estimates

Results for the seemingly unrelated regression described by equations (1a) and (1b) for the intraday bid-ask spread in the spot and three-month forward Euro-U.S. dollar market. The sample period is December 1, 1999 through December 31, 2000. The dependent variable is the median spread during a 15-minute interval. The independent variables are number of observations in the previous interval (*nobs*), realized volatility over the previous day (*volatility*), two dummy variables for the level of the spot and forward rate (*Price level 2* and *Price level 3*), dummy variables for each month as well as for the first and second halves of December and January, and dummies for the geographic trading regions. Each dummy variable is identified by the period or geographic region to which the dummy relates. The first column presents the estimated coefficients and the second column the corresponding (Newey-West) t-statistics. All coefficients are multiplied by 10,000 so they can be interpreted in terms of pips.

Independent variable	Spot Market		Forward Market	
	Coefficient	t-stat	Coefficient	t-stat
Intercept	5.302	94.73	6.040	82.40
Dummy Dec 1-15, 1999	-0.741	-11.50	-0.736	-8.18
Dummy Jan 1-15, 2000	0.298	3.24	0.153	1.47
Dummy Jan 16-31, 2000	-0.270	-3.27	-0.480	-5.10
Dummy February 2000	-0.993	-16.58	-0.979	-12.27
Dummy March 2000	-0.988	-16.79	-0.873	-10.78
Dummy April 2000	-1.241	-20.42	-1.147	-13.44
Dummy May 2000	-1.081	-16.78	-1.264	-13.73
Dummy June 2000	-0.840	-13.96	-0.787	-9.49
Dummy July 2000	-1.049	-17.84	-1.161	-14.43
Dummy August 2000	-1.071	-16.17	-1.276	-13.47
Dummy September 2000	-0.818	-11.38	-1.319	-12.64
Dummy October 2000	-0.888	-11.98	-1.187	-10.81
Dummy November 2000	-0.786	-10.57	-1.284	-11.53
Dummy Dec 1-15, 2000	-0.708	-10.19	-1.259	-12.47
Dummy Dec 16-31, 2000	-0.617	-9.67	-1.030	-10.90
Dummy Asian Markets	0.817	38.14	1.208	33.36
Dummy European Markets	0.094	5.28	-0.199	-6.21
Dummy European & North American Market Overlap	-0.295	-16.45	-0.412	-12.28
Dummy No Major Market	0.514	18.67	0.538	13.52
Nobs	-0.002	-34.57	-0.050	-22.49
Volatility	1.24	1.62	4.64	3.49
Price Level 2	0.020	0.63	0.138	2.52
Price Level 3	0.063	1.84	0.145	2.56
R-square	0.19		0.21	

Table 2: Tests of restrictions

Results from Wald tests of series of restrictions on the coefficient estimates from equations (1a) and (1b) for the intraday bid-ask spread for the spot and three-month forward Euro-U.S. dollar market. The sample period is December 1, 1999 through December 31, 2000. The test statistic is defined as $Z = (R\hat{\beta})'(R\Omega R')^{-1}(R\hat{\beta})$ which is distributed chi-square with degrees of freedom equal to the number of linear restrictions in *R*. The first column presents the Z-statistic and the second column the corresponding p-value.

Panel A. Tests of the equality of coefficients across the spot and forward markets.

The test is whether the coefficients on the dummies in the first column are equal across the spot and forward markets. For instance, the first row presents the statistic for the test that the (four) coefficients on the dummies for the first half of December 1999 and the first half of January 2000 in the spot and forward markets are equal.

Test of coefficients	Z-value	p-value
Dec 1-15, 1999 and Jan 1-15, 2000 equal	3.30	19.2%
Dec 1-15, 1999 through Jan 16-31, 2000 equal	7.72	5.2%
Jan 1-15, 2000 and Jan 16-31, 2000 equal	5.20	7.4%
February 2000 through August 2000 equal	49.88	0.0%
February 2000 through November 2000 equal	76.33	0.0%
February 2000 through December 2000 equal	112.47	0.0%
August 2000 through November 2000 equal	59.34	0.0%
August 2000 through December 2000 equal	63.12	0.0%

Panel B. Tests of the equality of the coefficients in each equation.

The test is whether the coefficients on the dummies in the first column are equal in the spot and forward markets, taken separately. For instance, the first row presents the statistic for the test that the coefficients on all the dummies in the spot and forward markets are equal.

Test of coefficients	Spot Market		Forward Market	
	Z-stat	p-value	Z-stat	p-value
All Calendar Dummies equal	799.2	0.0%	373.6	0.00%
All Y2K Dummies equal	236.5	0.0%	120.7	0.00%
All Non-Y2K Dummies equal	426.6	0.0%	444.7	0.00%
Feb 2000 through Aug 2000 equal	128.7	0.0%	93.8	0.00%
Sept 2000 through Dec 2000 equal	50.4	0.0%	11.3	2.36%
Dec 1-15, 1999=Jan 1-15, 2000	88.9	0.0%	42.1	0.00%
Dec 1-15, 1999=Jan 16-31, 2000	44.1	0.0%	9.0	0.27%
Jan 16-31, 2000=Feb 2000	116.8	0.0%	44.5	0.00%
Jan 16-31, 2000=Mar 2000	118.5	0.0%	26.8	0.00%
Jan 16-31, 2000=Apr 2000	206.1	0.0%	77.0	0.00%
Jan 16-31, 2000=Dec 1-15, 2000	42.3	0.0%	72.1	0.00%
Jan 16-31, 2000=Dec 16-31, 2000	23.4	0.0%	64.0	0.00%
Dec 1-15, 1999=Dec 1-15, 2000	4.0	4.6%	32.2	0.00%

Table 3. Daily regression estimates

Results for the seemingly unrelated regression described by equations (1a) and (1b) for the daily bid-ask spread in the spot and three-month forward Euro-U.S. dollar market. The model is suitably modified for daily data. The sample period is June 1, 1999 through December 31, 2003. The dependent variable is the daily spread. The independent variables are realized volatility over the previous 22 trading days (*volatility*), two dummy variables for the level of the spot and forward rate (*Price level 2* and *Price level 3*), and dummy variables for each month as well as for the first and second halves of December 1999. Each dummy variable is identified by the period to which the dummy relates. The first column presents the estimated coefficients and the second column the corresponding (Newey-West) t-statistics. To save space, only the average monthly coefficient and t-statistic are presented for the years 2001 to 2003. All coefficients are multiplied by 10,000 so they can be interpreted in terms of pips.

	Spot Market		Forward Market	
	Coefficient	t-stat	Coefficient	t-stat
Intercept	4.900	11.75	5.111	10.61
Dummy June, 1999	-0.873	-1.91	-0.484	-0.91
Dummy July, 1999	-0.676	-1.64	-0.201	-0.93
Dummy August, 1999	-0.841	-1.93	-0.512	-1.00
Dummy September, 1999	-0.423	-0.99	0.080	0.16
Dummy October, 1999	-0.752	-1.76	-0.271	-0.55
Dummy November 1999	-0.340	-0.82	0.156	0.34
Dummy Dec 1-15, 1999	-0.184	-0.40	0.183	0.32
Dummy January, 2000	-0.236	-0.56	-0.089	-0.21
Dummy February 2000	-1.003	-2.52	-0.091	-1.19
Dummy March 2000	-1.562	-4.44	-0.952	-2.44
Dummy April, 2000	-1.907	-5.17	-1.199	-2.99
Dummy May-00	-1.233	-2.95	-0.541	-1.23
Dummy Jun-00	-1.472	-3.82	-0.760	-1.68
Dummy Jul-00	-1.211	-3.50	-0.663	-1.75
Dummy Aug-00	-1.711	-4.37	-1.101	-2.63
Dummy Sep-00	-1.810	-4.26	-0.921	-1.82
Dummy Oct-00	-1.948	-4.55	-1.156	-2.51
Dummy Nov-00	-2.220	-5.80	-1.610	-4.11
Dummy Dec-00	-1.872	-4.52	-1.218	-2.73
Average Jan (2001-03)	-1.297	-3.32	-0.761	-1.62
Average Feb (2001-03)	-1.343	-3.28	-0.889	-1.95
Average Mar (2001-03)	-1.398	-3.49	-0.888	-2.00
Average Apr (2001-03)	-1.554	-3.69	-1.089	-2.34
Average May (2001-03)	-1.295	-3.29	-0.861	-2.01
Average Jun (2001-03)	-1.553	-4.06	-1.072	-2.50
Average Jul (2001-03)	-1.581	-3.91	-1.105	-2.47
Average Aug (2001-03)	-1.231	-3.22	-0.732	-1.64
Average Sept (2001-03)	-1.421	-3.77	-0.982	-2.28
Average Oct (2001-03)	-1.407	-3.76	-1.078	-2.57
Average Nov (2001-03)	-1.256	-3.27	-0.818	-1.89
Average Dec (2001-03)	-0.925	-2.18	-0.525	-1.09
Volatility	1.742	1.06	1.789	0.87
Price Level 2	0.388	1.71	0.478	1.43
Price Level 3	0.069	0.54	-0.392	-1.35
R-square	0.74		0.63	

Figure 1. Intraday spot bid ask spread, December 1, 1999-December 31, 2000

The dotted line is the graph of the intraday quoted bid-ask spread for the Euro-U.S. dollar spot contract over the period December 1, 1999 to December 31, 2000. The spread series consists of the median quote during 60-minute intervals. The solid line is a weekly moving average of spreads to smooth weekly and daily seasonalities.

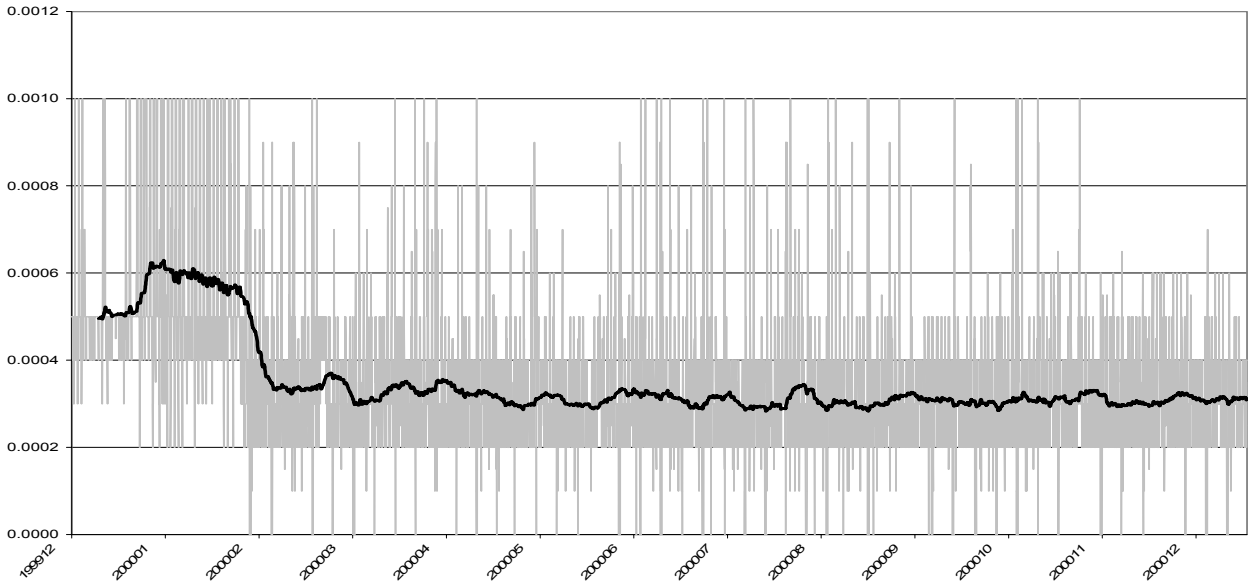


Figure 2. Intraday forward bid ask spread, December 1, 1999-December 31, 2000

The dotted line is the graph of the intraday quoted bid-ask spread for the Euro-U.S. dollar three-month forward contract over the period December 1, 1999 to December 31, 2000. The spread series consists of the median quote during 60-minute intervals. The solid line is a weekly moving average of spreads to smooth weekly and daily seasonalities.

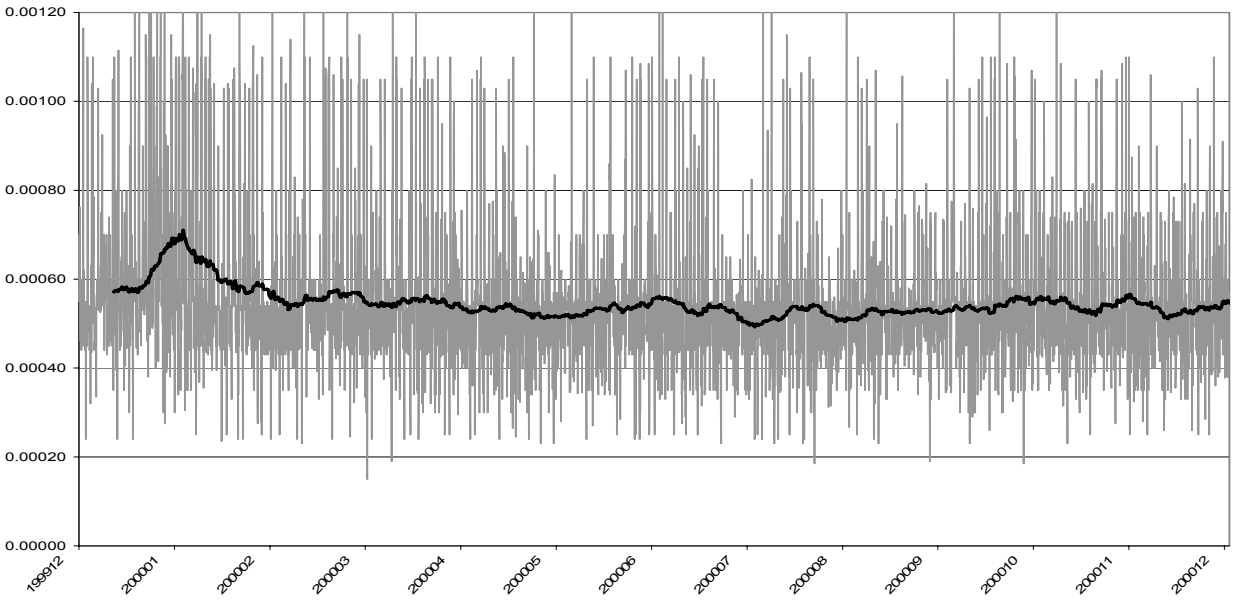
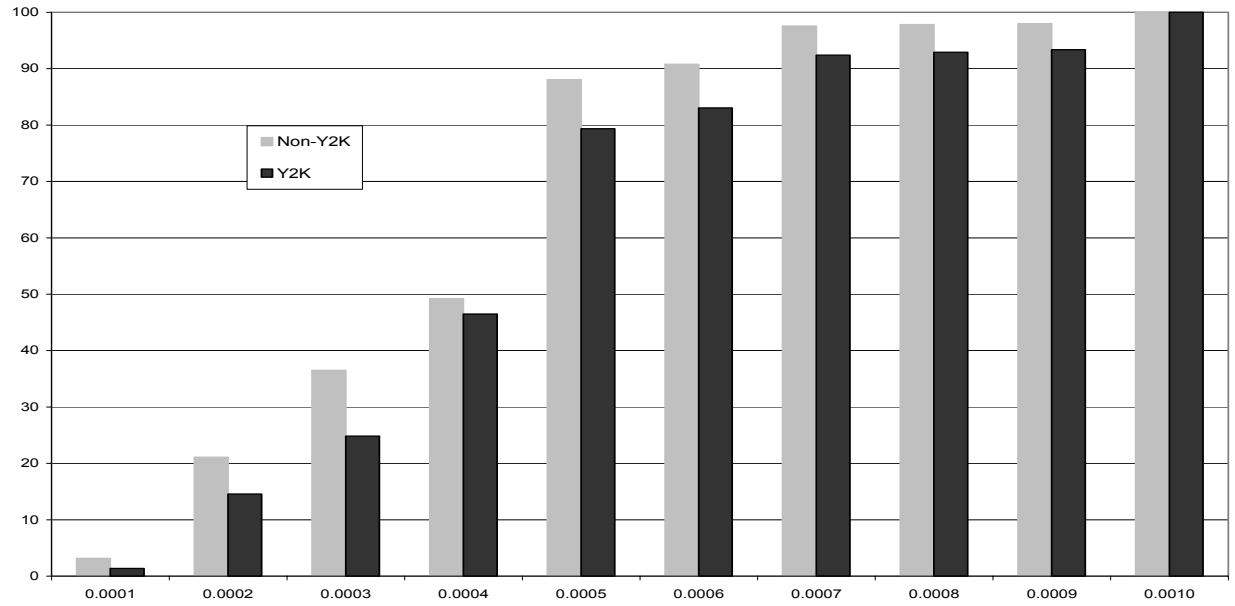


Figure 3. Cumulative spread distributions for the Y2K and non-Y2K periods

Graphs of the cumulative distribution of the median quoted bid-ask spread for the Euro-U.S. dollar spot and three-month forward contracts for the period around Y2K and for the non-Y2K period. The 13-month sample period (December 1, 1999 through December 31, 2000) is divided into two sub-periods, the period surrounding Y2K (December 1999 and January 2000) and the non-Y2K period (February 2000 through December 2000). The median spread is measured over 60-minute intervals. The black (gray) bars refer to the Y2K (non-Y2K) period. Panel A contains the histogram for the spot market, and panel B the histogram for the forward market.

Panel A. Spot spread



Panel B. Forward spread