Bank Trading Revenues, VaR, and Market Risk

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Abstract

Bank dealers play a central role in market-making in financial markets and are active traders in their own right. Recent literature has argued that trading activity and risk-taking by banks and other financial institutions may contribute to market volatility and illiquidity. The literature further suggests that institutions' wide-spread adoption of Value-at-Risk for risk management is one important source of destabilizing market behavior. This paper studies the market risks of 7 large U.S. trading banks based on the banks' daily trading revenues and VaRs. The study applies a linear factor model to bank trading revenues, with factors representing exchange rate, interest rate, equity, and credit markets. The analysis considers the size and direction of risk exposures across markets as evidenced in the trading revenues and commonalities in exposures across the 7 banks. There are also supplemental tests for non-linearity and time-variation in market exposures. Further consideration is given to the relation between bank VaRs and market factor volatility.

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A. Introduction

Bank dealers play a central role in market-making in financial markets and are active traders in their own right. Because of their importance, bank dealer risk exposures and trading activity are important to financial market stability. In recent literature it has been argued that trading activity by banks and other financial institutions may contribute to market volatility and illiquidity. Commonly cited episodes include various foreign exchange market crises between 1997 and 1999, the global bond market sell-off following the Russian debt default in August 1998 and the near failure of a large hedge fund in September 1998. The arguments center on risk taking and risk management strategies that lead to exaggerated market fluctuations.[1]

This literature further suggests that the widespread adoption of Value-at-Risk (VaR) in portfolio management is one important source of destabilizing behavior. VaR measures the potential for exceeding a specified loss based on forecasts of market volatility and the institution's market exposures. The argument is that VaRs will change with changes in market volatility and, in response, that risk managers will act in unison to increase and reduce their market exposures. Their joint actions will increase market fluctuations.

The reasoning in this literature is based largely on theoretical arguments and some episodic evidence. In particular, there has been little empirical study of the portfolio behavior or market risk taking of bank dealers.

In this paper, we undertake a study of the market risks of 7 large U.S. trading banks based on the daily trading revenues and VaRs measured at the consolidated bank holding company level. All of the banks meet the "large trader" criterion for Basel market risk capital requirements. Four were among the largest derivatives dealers worldwide and the remaining three among the top 10 U.S. dealers during the period of study. While data availability and hence sample sizes vary among the banks, the samples range from January 1998 through December 2003. The bank data is an extended sample of the data used in Berkowitz and O'Brien (2002).

[1] See for example Basak and Shapiro (2001), Danielsson, Shin, and Zigrand (2002), Morris and Shin (1999), Leipold, Trojani, and Vanini (2003), Persaud (2000). For a contrary argument on the effects of dynamic VaR-based portfolio management, see Cuoco and Liu (2003) .

Commercial banks and their holding company affiliates are the principal dealers in over-the-counter debt securities and derivatives markets and foreign exchange and they are substantially involved in equity trading. The size of their market risk exposures, as well as trading activity, are important to financial market stability. Large risk exposures could pose risks for the functioning of financial markets. Trading banks are also leading users of VaR in portfolio management. Several recent papers have studied bank VaRs.[2]

Berkowitz and O'Brien (2002) reported that VaRs for a small sample of large trading banks showed only modest increases during the market turbulence of August - September 1998. They also found that cross-bank VaR correlations show no clear pattern of co-movement. These observations contrast with arguments cited above on the market effects of VaR-based risk management.

In order to identify banks' market risks, we apply a linear market factor model to the banks' trading revenues. Factor models have a long history and broad application in identifying portfolio return relationships to market and economic factors. Notable applications include Chen, Roll, and Ross (1986) who attempt to identify systematic risks in stock returns. More directly related to our objectives are the "market-style" analyses that have been employed in mutual fund studies, first applied by Sharpe (1992). In the style analyses, the factors are asset returns for different market categories and the regression coefficients are intended to represent a fund's "market style," i.e., a portfolio of market securities that describes the fund's returns.

The factors used here are market indices for exchange rates, equity, default-free interest rates, and credit spreads. They are intended to capture general market price changes that would affect trading position values. Besides changes in position values, trading revenues also include fee, spread, and net interest income. An (equity) market volume measure is included to potentially capture the dependence of fee and spread income on the volume of trading activity.

The regression results indicate that market factors across the different categories have significant effects on bank trading revenues. However, the explanatory power of the market factors is low and the factor sensitivities are fairly modest for all 7 banks. For example, 2 standard deviation shocks to individual market factors typically produce about

[2] See Jorion (2002), Berkowitz and O'Brien (2002) and Hirtle (2003)

a .1 standard deviation change in a bank's trading revenue (mean 1-day trading revenues are .77 standard deviations for the median bank).

Trading revenues for the 7 banks are inversely related to interest rate factors, suggesting trading positions are net long in interest rate exposures. While trading revenues also depend on exchange, equity, and credit factors, coefficient signs and significance vary within and across the broad market categories for each bank and across banks for each factor. Overall, the linear market factor regressions indicate heterogeneity in exposures across markets and across banks.

Equity market trading volume has relatively large effects on trading revenues, with positive regression coefficients and statistical significance for 5 banks.

The linear market factor model is most appropriate for measuring market exposures when returns reflect a portfolio with a stable composition. This is a common characteristic of mutual funds. However, banks actively manage their trading portfolios, which can also be affected by their market-making activities. These features can create non-linear and time-varying exposures that the linear factor model will not properly reflect. Though for different reasons, active portfolio management also is a distinguishing feature of hedge funds. The linear factor model has not been particularly successful in measuring hedge fund market styles.[3]

Accounting for potentially complex and unspecified portfolio strategies is difficult, especially when there are a large number of market factors. Here we employ several limited supplemental tests to detect evidence of non-linear relationships that could have implications for market dynamics or volatility. One test looks for certain non-linear relations that would imply trading strategies that are related to market movements. The test results do not reveal evidence of non-linearities for exchange rate, equity, and credit factors but are more ambiguous regarding interest rate factors**.** A second test considers time-varying market exposures by estimating the factor regressions for different time periods. These results show evidence of time-varying exposures.

A test is then conducted to determine the potential influence of market factor volatility on bank VaRs. VaRs appear to have no more than modest power in forecasting near-term market volatility. This result contrasts with arguments that link market

[3] See especially Fung and Hsieh (1997), as well as Brown and Goetzmann (1997, 2001), Ackermann, McEnally, and Ravenscraft (1999), and references therein.

volatility to VaR-based risk management and raise a question of whether banks' condition their VaRs on forecasts of near-term market volatility.

The paper is organized as follows. In the next section, we describe our data sample and provide some descriptive statistics. The relationship between revenue and the market factors is studied in Section C, while that between reported VaRs and the market factors are reported in Section D. We conclude by summarizing our various findings and their implications for market stability issues.

B. Bank Data and Descriptive Statistics

The Basel Market Risk Amendment (MRA) sets capital requirements for the market risk of bank holding companies with large trading operations. Capital requirements are based on 99-percentile daily VaR estimates, which imply trading losses should exceed VaR with a probability of 1 percent. For model testing purposes, banks are also required to maintain historical daily trading revenue and 99-percentile VaRs with a 1-day horizon. We use the daily trading revenue and VaRs for 7 U.S. banks, consolidated across the holding company. The observation period is January 1998 - December 2003. Due to limited data availability, the observation period is shorter for some banks.[4] So as not to reveal dollar magnitudes, trading revenue and VaR are divided by the respective banks' sample standard deviations for trading revenue.

In Figure 1, kernel densities for the banks' (standardized) trading revenues are presented, with normal distributions shown for comparison. Bank trading revenues include revaluations of positions due to market price changes, income from market-making, and net interest income. As can be seen, trading revenues typically fall in a relatively narrow range with positive mean but with occasional large gains and losses—there is high kurtosis. Much if not all of the positive mean income likely comes from market-making income and net interest on trading positions. However, relatively little is known about the volatility of bank trading revenue and its relation to market risks.

Table 1 provides descriptive statistics on trading revenues. For the median bank, mean daily trading revenue is .77 standard deviations. The Table also indicates that as a quantile measure of trading risk, bank VaRs are conservative. Mean bank VaRs indicate

[4] Using a shorter historical period, data for 6 of the 7 banks were used in Berkowitz and O'Brien (2002).

a quantile value lower than the 1 percent quantile for 6 of 7 banks. Also, the frequency of losses in excess of VaR is less than 1 percent for all banks.

Some of the bank VaR conservativeness may due to omitting fee, spread, and net interest income. VaR's forecast only losses due to unexpected position revaluations and ignore other components of trading revenue. Ignoring the positive return on these other income components may make VaRs conservative. However, even if the banks' daily trading revenues are de-meaned and all trading revenue volatility is attributed to position revaluations, VaRs would still be conservative for the majority of the banks. Also, Jaschke, Stahl, and Stehle (2003) found VaRs for German banks to be conservative when measured against trading revenue limited to position revaluations.

While bank VaRs are conservative, they may still have power to forecast trading revenue volatility. As an indicator of forecast power, the last column in Table 1 presents correlations between daily VaRs and the absolute value of next-day trading revenue, with absolute value being used to proxy volatility. While the correlations are not very high, they are positive for 6 of 7 banks, with significance levels greater than .01 for 4 banks. This supports results from earlier studies using quarterly data that bank VaRs have forecast power for trading revenue volatility. [5] Whether this forecast power extends to volatility in financial markets is considered below.

C. Bank Trading Revenue and Market Factors

1. <u>The Market Factor Model</u>

Before presenting the empirical work, it will be useful to consider an expression for trading revenue and its major determinants in the form of a linear market factor model. Assume a dealer has positions in K different financial market assets. Positions in the assets can be held directly (cash positions) or indirectly in the form of financial derivatives. If the portfolio contains financial derivatives, these can be expressed in terms of an equivalent set of cash positions. Consider discrete changes in asset prices over a small time interval δt and define $r_k(t) \equiv \delta P_k(t) / P_k(t)$ as the rate of change (return) for asset k between t and $t + \delta t$. Also define $v_k(t)$ as the value of the position at t and assume that it is fixed over the interval δt. In representing fee plus spread income, define

[5] See Jorion (2002) and Hirtle (2003).

a market trading volume in asset category *k (*measured in some nominal unit) as $x_k(t)$ and assume that fee plus spread income is proportional to trading volume. Finally, let $u(t)$ denote other income not accounted for. This would include net interest income as well as portfolio revaluations due to idiosyncratic influences on position values. Using these definitions, trading revenue equals

$$(1) \qquad R(t) = \sum_{k=1}^{K} \left[v_k(t) r_k(t) + f_k(t) x_k(t) \right] + u(t)$$

Equation (1) can be represented by a factor model that is linear in the factors $r_k(t)$ and trading volume $x_k(t)$, conditional on asset positions $v_k(t)$ and $f_k(t)$ (fee and spread income per unit of market trading volume). In the standard application of factor models, the factor loadings are constant and represent a fixed portfolio composition, e.g. $v_k(t) = v_k$. This is appropriate for typical mutual funds that follow a passive portfolio management strategy. Bank trading portfolios, however, are actively managed and can be affected by market-making activities. As a result, positions are not fixed over time and may be related to market factors, such as occurs when assets are held indirectly in the form of options or through dynamic portfolio management.

When positions are variable, the expected values of the regression coefficients will equal the expected or average positions plus a component that depends on the covariances between the positions and the market factors. Thus, the coefficients expected values need not reflect day-to-day or even average market exposures. For example, an average position of zero when day-to-day positions are either positive or negative, would not reflect day-to-day market risk exposures. Also, dynamic portfolio management or options positions can produce co-movement between positions and market factors that leads to non-linear relationships between trading returns and market factors. While we employ the linear factor model, these potential limitations motivate additional tests.

2. Linear Factor Regressions

In estimating trading revenue market exposures, 11 market factors are used to represent four broad market categories: exchange rates, default-free interest rates, equity, and credit spreads. The individual factors, with daily mean changes and standard deviations, are listed in Table 2a. As shown in the Table, daily mean changes are mostly close to zero, with the coverage period being January 1998 - December 2003. Regional exchange rate factors are a weighted average of selected country exchange rates. The country weights, shown in Table 2b, are based on world-wide dealer FX spot and derivatives turnover reported in tri-annual BIS Central Bank Surveys in 1998 and 2001. For the first three sets of factors, positive differences indicate increases in asset values; and for the last two, negative differences indicate increases in asset values.

A measure of daily market trading volume is also used to capture the effects of trading volume on dealer fee and spread income. We have no direct information on dealers' daily transactions volume. Detrended daily volume on the NYSE plus NASDAQ is used to represent a market volume influence on trading revenue. Also, we have no data on net interest income from trading positions and treat this as an unmeasured component of trading income.

Using the market factors and trading volume as regressors, linear regression equations were estimated for each of the 7 banks (standardized) dollar trading revenues. Regressions are estimated using OLS and include the 11 market factors, equity volume, lagged trading revenue, and a trend variable. Regression coefficients and t-statistics are presented in Table 3a. Table 3b reports F-statistics for the joint significance of all market factors and for each broad market category. Due to differences in the historical periods for which individual bank data is available, regression sample periods differ among the banks.

The regression R^2s in Table 3a indicate much of the variation in bank trading revenues is not explained by the regressors. However, the F-statistics for all market factors combined shown in Table 3b are significant at the 5% level for all but bank 7. F-statistics for individual market categories also are frequently significant—for 4 of 7 banks for each market category except for credit spreads.

To facilitate discussion of the quantitative importance of the market factors and equity volume on trading returns, the regression coefficients reported in Table 3a for these variables are multiplied by a 2 standard deviation shock to the respective factor. Since bank trading revenues are expressed as a fraction of the sample standard deviation of trading revenue, the scaled coefficients measure the number of standard deviations that trading revenues change due to 2 standard deviation shocks to the market factors.

The weighted factor coefficients indicate that bank trading revenues are not highly sensitive to individual market factor shocks. The greatest factor sensitivities are equal to about .3 standard deviation changes in trading revenue for a 2 standard deviation market factor shock, with a single outlier sensitivity of .4. About two-thirds of the factor sensitivities are less than .1 trading revenue standard deviations. The median value for the means of the 7 banks daily trading returns is .77 trading revenue standard deviations (see Table 1). Two standard deviation shocks to a single market factor, or even several market factors, typically would still leave a positive trading return.

For the two interest rate factors, coefficients across the 7 banks are almost all negative, implying that trading revenues decrease with increases in interest rates. The negative coefficients indicate banks hold net long interest rate trading positions, i.e., net positive durations. In quarterly statements, banks consistently report positive net interest earnings on their trading accounts and large asset positions in debt securities, which is consistent with interest rate positions being persistently net long.

For exchange, equity and credit market categories, however, the regression coefficients do not reveal a clear pattern of directional exposures to market factors. Factor signs vary within and across broad market categories for a given bank and across banks for a given factor.

Effects of market shocks will differ across banks because of heterogeneity among market exposures, implying that bank dealers should not be treated as a homogeneous group of market traders.

To quantify the cross-bank heterogeneity implied by the estimated regression coefficients, we calculate conditional correlations across bank trading revenues from historical simulations. Each bank's estimated factor loadings are multiplied by the historical factor values and cross-bank correlations are determined. These correlations condition on the estimated factor loadings in order to intentionally abstract from sampling uncertainty. They represent a convenient way of interpreting and summarizing the information contained in the regression results. The correlation coefficients are shown in Table 4.

The results in Table 4 are generally consistent with cross-bank heterogeneity in market exposures but the story is a little more involved. For banks 1 and 2, banks 1 and 5, and banks 2 and 5, the correlations implied by the estimated market factor coefficients are positive and high. Thus, for some pairs of banks, the estimated exposures to market risks imply highly correlated returns.

These correlations differ from those reported in Berkowitz and O'Brien (2002), which are based on correlations from actual trading revenues, i.e., unconditional correlations. Those correlations were all positive but small (results are similar with the extended sample data used here). The substantial differences between the conditional and unconditional correlations may indicate unmeasured variables which explain variation in individual bank trading revenues. It is also the case that cross-bank correlations using the factor model regression equation residuals are smaller than the unconditional correlations but continue to be positive.

Turning to equity volume, coefficients are positive for all 7 banks, with t-statistics significant at or close to a 1 percent level for 5 banks. The positive coefficients would be consistent with market-making activity whose profitability is dependent on market trading volume. The trading volume effects, using the scaled regression coefficients, are typically larger than the effects of individual market factors.

Lastly, the coefficients on the lagged dependent variable indicate some autocorrelation in trading revenue for 5 banks. It is difficult to know the source of this autocorrelation. Possible explanations are omitted components of trading income such as changes in the size of the market-making business or net interest income which tend to be persistent. Alternatively, it could indicate a lagged adjustment process such as the gradual reporting of portfolio revaluations and/or gradual recognition of fee income.

3. <u>Testing for Non-Linearity and Time Varying Positions</u>

As indicated in equation (1), the linear regression may not adequately account for a non-linear or time-varying relation between trading revenues and market factors. Further, these relationships may reflect portfolio management policies that have implications for market stability. Accounting for potentially complex and unspecified portfolio strategies is difficult, especially involving a large number of market factors. Here we undertake limited supplemental tests that consider a non-linear relationship that derives from portfolio management that is correlated with market returns and temporal variation in market factor exposures

Non-Linear Test

The first test is for non-linear trading policies that produce gains (or losses) in both up-markets and down-markets, i.e., U-shaped or inverse U-shaped return patterns. In these cases, linear regression coefficients could be close to zero, obscuring the existence of a nonlinear relationship. Alternatively, managers may protect against market moves in only one direction (e.g., portfolio insurance). If so, a linear regression will be unable to capture the convexity in the relation between trading returns and market returns. Empirical evidence of such trading return patterns would imply portfolio management that is related to market movements.

The following illustrates how such relations might have implications for market stability. Suppose through dynamic portfolio management or options strategies, dealers profit in rising markets by buying as prices increase and by selling as prices decrease, producing a U-shaped return pattern. This behavior may add to market volatility by adding to bull markets and bear markets. Alternatively, suppose dealers incur losses by selling from their portfolios in rising markets and buying in declining markets, producing an inverse U-shaped return pattern. This behavior could have countervailing effects on bull and bear markets. Dynamic hedging also may have effects on market stability as (long) risky exposures are expanded in rising markets and reduced in declining markets.

The test here considers these potential non-linear trading return relationships at the market category level by combining factor changes within each broad market category (e.g., exchange rates). For each market factor in a market category, days for which the factor falls into the low 20 percentile values and into the high 20 percentile values are sorted. For the market category as a whole, a day where one or more of its market factors is in the low 20 percentile and none are in the high 20 percentile is characterized as a low market (large negative) return day. A day where one or more market factors is in the high 20 percentile and none is in the low 20 percentile is characterized as a high market (large positive) return day. (Information on the factor values sorted by low and high market category returns is provided in Table 5).

Mean and median bank trading revenue, conditioned on low, average, and high return days for each market category are reported in Table 5. The mean and median income for "average" market return days are the banks' unconditional mean and median trading revenues, i.e., those from the banks' entire samples. The significance test for mean differences is based on a standard difference in two means test. For the median difference, it is based on the Mann-Whitney-Wilcoxon rank sum test for large samples.

The results shown in the Table do not give any clear evidence of U-shaped trading return relations, inverse U-shaped relations, or one-sided loss protections for the exchange rate, equity, and credit market factors. For the interest rate category, trading revenues are highest on days when interest rate declines are relatively large. However, on days of relatively large interest rate increases, mean and median trading revenues are similar to the full sample mean and median values. This would be consistent with hedging against interest rate increases. With the possible exception of interest rates, the trading revenue – market return relationships do not indicate non-linear portfolio strategies correlated with market returns.

Time Varying Positions

If portfolio positions vary over time and are independent of the market factors, the coefficients will be unbiased estimates of the portfolio's average daily market exposures. However, we are also interested in the variability of market exposures and whether exposures may vary dramatically or risks be substantially different from what appears based on average market exposures.

To consider the variability of trading portfolio positions, the sample was split at the end of 2000 for the 4 banks that have observations from 1998 to 2003 (or most of 2002 for bank 6). The regression results are presented in Table 6a. In the top part of Table 6b, F-statistics on the significance of market factors in each sub-sample are presented. In the bottom part, Chow tests on the significance of the differences in market factor coefficients between the two samples are reported. We summarize these results and implications regarding time-varying market risk exposures.

In several important respects, the results in the two sub-samples shown in Tables 6a and 6b re-enforce conclusions reached from the full sample results shown in Table 3a and 3b. The F-statistics in Table 6b indicate that the market factors have significant effects on trading revenues in both sub-samples, although significance is noticably stronger in the later period. Market factor exposures continue to be different across the 4 banks in the sub-samples for the non-interest rate market categories. Also, the historical periods for the first sub-sample and the full sample periods for banks 1 and 2 (Table 3) approximately match. Comparing the results for the 6 banks over the common sample period, it is clear that heterogeneity in market exposures observed using each bank's full sample period (Table 3a) cannot be attributable to different sample periods.

The sizes of market factor exposures in the two sub-periods are of the same general magnitude as those for the full sample. However, market exposures in both interest rates and credit spreads are substantially higher and more significant in the 2001 – 2003 sample than in the earlier period or in the full sample and, as noted, F-values for the market factors are higher in the later period. The different exposure levels for interest rate and credit factors are one instance of time varying market exposures. There also are less systematic differences in the exposures of other factors between the two samples. The Chow test at the bottom of Table 6b measures the joint significance of the differences in the market factor exposures between the two samples. The results indicate that for banks 3 and 5, the hypothesis of unchanging market exposures is rejected at the .05 level and for bank 4 at the .12 level. The comparisons of market factor coefficients between the two time periods give evidence of time varying market exposures.

D. Bank VaRs and Market Factors

During the period between August and September 1998, bank trading returns were highly volatile and significant losses were incurred. Berkowitz and O'Brien (2002) observed that during this period, bank VaRs showed only modest increases. This would suggest that bank VaRs may not be very sensitive to near-term market volatility. Further, cross-bank VaRs show no systematic co-movement (Berkowitz and O'Brien (2002), as well as with the data used here). These observations are contrary to reasoning underlying arguments that VaR-based risk management has increased market volatility. Here we look at whether bank VaRs are different between periods of low and high market volatility over the entire sample periods for each of the 7 banks.

For this test, market "volatility" is measured by absolute market factor changes and the test is done at the market category level. For each broad market category, days of large absolute market changes and days of small absolute market changes are identified. Days of large (small) absolute market changes are days where the absolute value for at least one factor belonging to the market category is in the upper (lower) 20 percentile and none are in the lower (upper) 20 percentile (the footnote to Table 7 summarizes market factor sorting by small and large market volatility days).

As a prelude to the VaR test, means and medians for bank trading revenue volatility (absolute daily trading revenue) conditioned on high and low volatility days for each market category are presented in Table 7. For the 7 banks and the 4 market categories, the vast majority of trading revenue volatility means and medians are higher on high market volatility days than on low market volatility days. Also, differences in means and medians between the high and low market volatility samples typically are significant at the .05 level. The results in Table 7 strongly indicate that banks' trading revenue volatility is related to market volatility.

For the VaR test, the banks' 1-day VaR forecasts are conditioned on the same high and low market volatility days that were used in the trading revenue volatility tests above. The conditional mean and median VaRs are reported in Table 8. The Table contains 28 cells (4 market categories and 7 banks). Across market categories and banks, mean VaRs on days of high market volatility are above mean VaRs on days of low market volatility 53 percent of the time (15/28). Median VaRs are higher on days of high market volatility 60 percent of the time (17/28). Thus there is modest tendency for bank VaRs to be higher on days of high market volatility.

Differences between VaRs on days of high versus low market volatility also are statistically significant more frequently than might be expected by chance. Nonetheless, as can be seen visually from Table 5, the differences in the means and medians between the high and low market volatility days are modest.

Based on these results, bank VaRs appear to have no more than modest power in forecasting market volatility. This may indicate that bank VaRs are not strongly conditioned to forecast near-term market volatility. Basel standards for bank VaRs would be consistent with this feature. Regulatory standards require a minimum historical sample period for market factors of one year with any time-weighting of observations yielding not less than a 6 month average lag.

As reported in Table 1, bank VaRs are correlated with 1-day ahead trading revenue volatility. Adequately explaining this correlation would require formal analysis. However, as discussed earlier, trading revenue volatility depends on trading portfolio market exposures and market volatility. While the results in Table 7 indicate that the volatility of bank bank trading returns is related to market volatility, the results in Table 8 suggest that the relationship between bank VaRs and market volatility is not very strong. Since daily VaRs are conditioned on current end-of-day positions, if changes in positions have persistence, this may give bank VaRs power in forecasting trading revenue volatility. Moreover, if variation in trading portfolio market exposures tends to be bank specific, there may not be systematic cross-bank co-movement in their VaRs.

E. Conclusions

Bank dealers play a central role in market-making in financial markets. In recent literature it has been argued that risk-taking and trading activity by banks and other financial institutions may contribute to market volatility and illiquidity. This study represents a first attempt to supplement the literature with a systematic empirical study of market risks using daily trading revenues and VaRs for 7 large U.S. trading banks.

Applying a linear market factor model, we find that bank trading revenues are inversely related to interest rate factors, which is consistent with trading positions being net long in interest rate exposures. In addition, daily equity market trading volume has a significant positive influence on trading revenues, consistent with the hypothesis that trading revenue depends on market trading volume through banks' market-making activity. This feature may differentiate the trading returns and behavior of banks from that of other institutional market participants, such as hedge funds.

Overall, the explanatory power of the market factors is low and the sensitivities of banks' trading revenue to market factors are modest. For exchange rate, equity and credit spread factors, the estimated sensitivities also vary in sign across factors and across banks for a given factor. The results indicate heterogeneity in both individual banks' exposures across markets and market exposures across banks, although for some pairs of banks market exposures may still be highly correlated.

Acknowledging that active portfolio management can create nonlinear exposures, the weak sensitivity of trading revenue to market factors may at least partly be the result of using a linear model. In a limited test, we did not find strong evidence of a non-linear relationship between trading revenue and the factors. The linear model also will not reflect variation in banks' market risk exposures. Applying the linear factor model to two sub-samples, there were noticeably higher exposure levels in some market factors in the later sample and, for some banks, we are able to statistically reject the assumption that market exposures are constant. While the results indicate time varying exposures, the general magnitudes of estimated exposures were still not large in either period.

In a final test, while we find that bank trading revenue volatility is relatively high in times of high market volatility, bank VaRs show no more than modest power in forecasting market volatility. This finding may indicate that bank VaRs are not strongly conditioned on forecasts of near-term market volatility.

These results bear on issues concerning bank trading portfolio risk and behavior and market stability. Maintaining relatively modest exposures with differences in the direction of exposures across markets puts bank dealers in a favorable position to withstand large unexpected and even broad-based market fluctuations. Also, a common feature of market destabilizing arguments is the homogeneous treatment of trading institutions. Our results suggest that there may be significant heterogeneity in the risk exposures of bank trading portfolios, which makes the aggregate market effects of trading banks less clear. Further, our results indicating that bank VaRs have limited power in forecasting market volatility are not consistent with arguments that banks' use of VaR is a catalyst for market destabilizing behavior, as these arguments assume a strong relation between VaR and market volatility.

In considering these results, it is important to keep in mind that this study is only an initial effort to characterize market risks in bank trading portfolios and is limited to a small number of banks. Also, the linear factor model, while widely used in portfolio risk analysis, has important limitations and its adaptability to trading portfolios is still uncertain.

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Table 1. Descriptive Statistics on Bank Trading Revenue and VaR[1]

			Trading Revenue				VaR		
Bank	Dates	Obs	Mean	Excess Kurtosis	Skewness	One Percentile	Mean (neg)	violation rate	Correlation $(VaR_t, \lvert TR_{t+1}\rvert)$
1	1/98 - 12/00	762	1.05	10.75	-0.60	-1.73	-1.94	0.4[a]	0.05
2	1/98 - 9/00	711	0.79	4.82	0.16	-1.96	-1.70	0.8	0.1**
3	1/98 - 9/01	1524	0.77	13.13	1.49	-2.20	-4.07	0.4**	-.06*
4	1/98 - 12/03	1544	0.90	4.17	0.46	-1.60	-7.04	0**	0.3**
5	1/98 - 12/03	1551	0.62	6.46	-0.62	-2.45	-4.19	0.3**	0.05
6	1/98 - 6/02	1166	0.72	79.64	-3.98	-1.37	-2.08	0.3**	0.1**
7	10/98 - 3/01	626	0.39	81.05	0.57	-1.29	-2.74	0.2**	0.1**

1. Trading revenue and VaR are divided by trading revenue standard deviation. ** significant at .01; * significant at .05.

[a] Significant at .06.

Table 2. Market Factors

2a. Market Factors[1]

Exchange Rates	mean (std dev) % change	Interest Rates	mean (std dev) % change	Equity Returns	mean (std dev) % change	Credit Spreads[2]	mean (std dev) % change
W Europe	0.009	6-mo	-0.003	NYSE	0.012	10-yr	0.000
(we)	(0.558)	T-bill	(0.045)		(1.156)	Baa spd	(0.035)
E Europe (ee)	-0.107	10-yr	-0.001	NASDAQ	0.015	5-yr	0.000
	(2.274)	Treas	(0.06)		(2.222)	hi yld spd	(0.093)
Asian Paci (ap)	0.012					10-yr	0.000
	(0.603)					swp spd	(0.032)
S America (sa)	-0.037						
	(0.603)						

2b. Exchange Rates (with U.S. dollar)[2]

W Europe (1998)		W Europe (1999 – 02)		Asian Pacific		South America		E Europe	
country	weight	country	weight	country	weight	country	weight	country	weight
Germany	0.54	Euro	0.633	Japan	0.727	Mexico	0.658	Russia	1
UK	0.198	UK	0.222	Austral	0.136	Brazil	0.342		
France	0.092	Switzer	0.102	HK	0.075				
Switzer	0.127	Sweden	0.043	Sing	0.035				
Sweden	0.043			Korea	0.027				

1 Market factors are calculated at a daily frequency for 1998-2003. Factors are expressed as 1-day log differences and percentage first differences. Observations for all factors are omitted on any day a single factor is missing. There were 18 missing days and a remaining total of 1471 observations. On missing days, changes are based on the two observed adjacent days. Credit spreads are with respect to Treasury rates of the same maturity

2. Regional exchange rates are weighted log differences. Weights are based on world-wide dealer FX Spot and derivatives turnover volume reported for different currencies. Turnover volume is taken mostly from the 2002 BIS Central Bank Survey. The survey date is June April 2001. However, June 1998 turnover volume from the 1999 Central bank Survey, is used to determine weights for Western Europe currencies for pre-Euro 1998 (country coverage in the 1998 survey is limited).

Table 3a Trading Revenue Market Factor Regressions[1]

	Variable	Bank 1	2	3	4	5	6	7
b_0		0.619	0.429	0.247	0.442	0.111	0.532	0.393
t		8.381	5.629	5.238	8.984	2.228	8.725	4.788
b_1	x_{we}	0.056	0.090	0.083	0.095	-0.065	0.043	-0.050
t		0.755	1.132	1.628	1.870	-1.185	0.669	-0.631
b_2	x_{ee}	0.109	0.029	0.253	0.039	0.067	0.023	-0.424
t		2.214	0.574	5.464	0.854	1.352	0.457	-2.941
b_3	x_{ap}	-0.283	-0.137	-0.058	0.031	-0.012	0.021	-0.040
t		-4.479	-2.100	-1.167	0.633	-0.227	0.350	-0.499
b_4	x_{sa}	-0.056	-0.171	0.082	0.104	-0.086	0.121	-0.025
t		-0.787	-2.317	1.735	2.193	-1.697	1.935	-0.311
b_5	nyse	-0.285	-0.290	0.081	0.318	-0.142	-0.064	-0.027
t		-2.851	-2.736	1.170	4.580	-1.909	-0.710	-0.239
b_6	nasdaq	0.141	0.219	0.053	-0.098	0.051	-0.053	0.074
t		1.531	2.062	0.769	-1.418	0.687	-0.654	0.798
b_7	r_{6m}	-0.145	-0.016	-0.086	0.018	-0.088	-0.235	-0.017
t		-1.847	-0.186	-1.537	0.327	-1.469	-3.562	-0.204
b_8	r_{10y}	-0.209	-0.022	-0.296	-0.070	-0.149	-0.054	-0.200
t		-1.667	-0.154	-4.202	-0.997	-1.981	-0.595	-1.520
b_9	moody spd	-0.038	0.156	-0.167	0.069	0.001	0.115	-0.073
t		-0.365	1.401	-2.481	1.030	0.010	1.353	-0.683
b_{10}	hy spd	-0.044	0.083	-0.202	-0.050	-0.143	-0.291	-0.149
t		-0.345	0.521	-2.875	-0.717	-1.915	-3.308	-1.160
b_{11}	swap spd	-0.009	0.037	0.045	0.001	0.043	-0.014	0.119
t		-0.129	0.495	0.958	0.028	0.843	-0.229	1.611
b_{12}	mkt volume	0.493	0.366	0.253	0.592	0.067	0.327	0.089
t		3.113	2.074	3.179	7.410	0.789	2.985	0.565
b_{13}	Tr Rev_{t-1}	0.146	0.230	0.293	0.362	-0.037	-0.011	0.131
t		4.066	6.134	11.904	15.246	-1.428	-0.359	3.251
b_{14}	trend	0.0008	0.0005	0.0004	0.0002	0.0007	0.0004	-0.0002
t		4.8824	2.8889	7.1667	3.3333	12.3333	3.8889	-0.7727
F-Stat		8.742	6.560	29.692	30.397	12.769	4.377	2.323
R^2		0.146	0.121	0.223	0.227	0.110	0.053	0.051
N		729	682	1,463	1,464	1,463	1,111	621

1. Trading revenue is normalized by the banks' trading revenue standard deviations. Market factor and trading volume coefficients are scaled by 2 standard deviations for the respective variables. Coefficients measure the number of standard deviation chnages in trading revenue from a 2 standard deviation change in the respective market factors and trading volume. t-values are below coefficients.

Table 3b. F-Tests For Trading Revenue Market Factor Restrictions[1]

	Market Factors = 0		Exchange Factors= 0		Equity Factors= 0	
Bank	F	F*(5%)	F	F*(5%)	F	F*(5%)
1	4.92	1.80	7.18	2.38	4.09	3.01
2	3.08	1.80	3.09	2.39	3.73	3.01
3	6.61	1.80	9.08	2.38	3.17	3.00
4	3.72	1.80	2.52	2.38	13.60	3.00
5	1.98	1.80	1.57	2.38	2.23	3.00
6	2.68	1.80	1.13	2.38	1.47	3.00
7	1.39	1.80	2.28	2.39	0.37	3.01

	Interest Factors = 0		Credit Factors = 0	
Bank	F	F*(5%)	F	F*(5%)
1	3.87	3.01	0.10	2.62
2	0.03	3.01	1.01	2.62
3	11.01	3.00	6.68	2.61
4	0.51	3.00	0.43	2.61
5	3.49	3.00	1.58	2.61
6	7.00	3.00	3.66	2.61
7	1.27	3.01	1.51	2.62

1. F-values(n_1 = number of restrictions in each market category, n_2 = sample size - 15.)

Table 4. Cross-Bank Correlations Implied by Historical Market Factors and Estimated Bank Factor Coefficients

Bank	1	2	3	4	5	6	7
1		0.754	0.261	-0.403	0.748	0.296	-0.132
2			-0.195	-0.474	0.620	0.060	-0.054
3				0.474	0.226	0.250	-0.365
4					-0.430	0.081	-0.078
5						0.407	-0.037
6							-0.020

1. Cross-bank trading revenue correlations are calculated from historical simulations based on the 1998 - 2003 sample of daily market factor values and the estimated bank factor regression coefficients reported in Table 3b.

Table 5. Bank Trading Revenue Conditioned on Low, High, and Average Market Factors[1]

Exchange Rate Conditioning

	Low	Average	High	Low	Average	High
Bank	Trading Revenue Mean			Trading Revenue Median		
1	1.14	1.05	1.04	1.07	1.00	0.97
2	0.87	0.79	0.85	0.82	0.75	0.78
3	0.70	0.77	0.81	0.70	0.75	0.75
4	0.85	0.90	0.98*	0.81	0.78	0.81
5	0.60	0.62	0.61	0.55	0.58	0.59
6	0.63	0.72	0.69	0.63	0.66	0.68
7	0.51	0.39	0.39	0.36	0.32	0.32

Interest Rate Conditioning

	Low	Average	High	Low	Average	High
Bank	Trading Revenue Mean			Trading Revenue Median		
1	1.29*	1.05	1.00	1.22*	1.00	0.90
2	0.93	0.79	0.85	0.82	0.75	0.80
3	0.86*	0.77	0.71	0.90*	0.75	0.72
4	0.95	0.90	0.93	0.87	0.78	0.78
5	0.69*	0.62	0.57	0.70*	0.58	0.55
6	0.87*	0.72	0.63	0.81*	0.66	0.64
7	0.49	0.39	0.42	0.33	0.32	0.40

Equity Conditioning

	Low	Average	High	Low	Average	High
Bank	Trading Revenue Mean			Trading Revenue Median		
1	1.17	1.05	1.06	1.06	1.00	0.89
2	0.93	0.79	0.77	0.86	0.75	0.78
3	0.74	0.77	0.86	0.78	0.75	0.85
4	0.83	0.90	1.20*	0.80	0.78	0.93*
5	0.60	0.62	0.51	0.59	0.58	0.45
6	0.82	0.72	0.72	0.75	0.66	0.75
7	0.33	0.39	0.33	0.29	0.32	0.32

Credit Spread Conditioning

	Low	Average	High	Low	Average	High
Bank	Trading Revenue Mean			Trading Revenue Median		
1	1.00	1.05	1.13	0.93	1.00	1.13
2	0.72*	0.79	0.92	0.64*	0.75	0.84
3	0.84	0.77	0.73	0.76	0.75	0.78
4	1.01	0.90	0.91	0.85	0.78	0.83
5	0.68	0.62	0.63	0.64	0.58	0.61
6	0.73	0.72	0.73	0.66	0.66	0.77
7	0.42	0.39	0.42	0.32	0.32	0.36

1. Bank trading revenue is normalized by bank trading revenue standard deviations. Sample sizes for "Low" and "Hi" categories range from 167 to 606, depending on the bank. Average refers to full sample means and medians. For each market category, the "Average" factor values are presented in Table 2. "Low" and "High" values for exchange rates factors had respective means and medians of roughly +1 and -1 standard deviation from the full sample averages (slightly less for exchange rates).
* Significant at .05 for differences between High and Low mean (median) trading revenue. Significance for the mean difference uses a standard diference of two means test. The medians test is the Mann-Whitney-Wilcoxon rank sum test for large samples.

Table 6a. Trading Revenue Market Factor Regressions for Subsamples[1]

Sample period: 1998 - 2000

		Bank			
	Variable	3	4	5	6
b_0		0.25	0.44	0.11	0.53
t-value		0.40	-2.59	3.65	6.39
b_1	x_{we}	-0.04	0.11	-0.13	-0.02
t-value		-0.65	1.95	-1.61	-0.27
b_2	x_{ee}	0.23	0.03	0.06	0.01
t-value		5.49	0.91	1.20	0.28
b_3	x_{ap}	-0.03	0.02	-0.02	0.07
t-value		-0.64	0.45	-0.32	1.07
b_4	x_{sa}	0.06	0.09	-0.16	0.07
t-value		0.98	1.69	-2.11	0.90
b_5	nyse	0.16	0.28	-0.11	-0.09
t-value		1.89	3.61	-1.07	-0.89
b_6	nasdaq	0.04	0.07	0.06	0.03
t-value		0.50	0.92	0.60	0.32
b_7	r_{6m}	0.16	0.13	0.13	-0.19
t-value		2.44	2.16	1.61	-2.37
b_8	r_{10y}	-0.26	-0.08	-0.22	-0.11
t-value		-2.37	-0.78	-1.67	-0.85
b_9	noody sp	-0.12	0.11	-0.10	-0.03
t-value		-1.38	1.35	-0.86	-0.27
b_{10}	hy spd	-0.35	-0.17	-0.14	-0.24
t-value		-3.15	-1.71	-1.04	-1.77
b_{11}	swap spd	0.08	0.05	0.12	0.04
t-value		1.40	0.89	1.65	0.49
b_{12}	TR_{t-1}	0.29	0.36	-0.04	-0.01
t-value		12.22	3.71	-1.38	1.54
b_{13}	trend	0.000	0.000	0.001	0.000
t-value		5.73	14.67	1.18	2.94
b_{14}	equity vol	0.29	0.75	0.08	0.19
t-value		4.19	11.38	0.91	2.29
F-Stat		30.06	45.78	1.49	2.11
R^2		0.37	0.47	0.03	0.04
N		744	744	744	744

Sample period: 2001 - 2003

		Bank			
	Variable	3	4	5	6
b_0		0.25	0.44	0.11	0.53
t-value		13.08	15.17	8.47	6.60
b_1	x_{we}	0.21	0.13	-0.06	0.15
t-value		2.46	1.66	-0.66	1.30
b_2	x_{ee}	0.16	-0.65	-2.81	-0.87
t-value		0.13	-0.55	-2.24	-0.48
b_3	x_{ap}	-0.11	-0.01	0.01	-0.09
t-value		-1.14	-0.09	0.09	-0.70
b_4	x_{sa}	0.06	0.11	-0.02	0.20
t-value		0.78	1.67	-0.24	1.74
b_5	nyse	0.01	0.48	-0.16	-0.03
t-value		0.11	4.49	-1.43	-0.17
b_6	nasdaq	0.17	-0.25	0.02	-0.16
t-value		1.41	-2.14	0.20	-1.08
b_7	r_{6m}	-0.44	-0.20	-0.45	-0.29
t-value		-4.60	-2.23	-4.64	-2.36
b_8	r_{10y}	-0.38	-0.12	-0.11	0.00
t-value		-3.93	-1.27	-1.13	-0.01
b_9	noody sp	-0.29	-0.08	0.02	0.30
t-value		-2.90	-0.81	0.20	2.08
b_{10}	hy spd	-0.27	-0.13	-0.24	-0.45
t-value		-2.79	-1.39	-2.44	-3.48
b_{11}	swap spd	0.09	-0.03	0.01	-0.03
t-value		1.16	-0.47	0.18	-0.25
b_{12}	TR_{t-1}	0.29	0.36	-0.04	-0.01
t-value		2.52	4.39	-1.75	-2.12
b_{13}	trend	0.000	0.000	0.001	0.000
t-value		-3.06	-7.50	7.39	0.61
b_{14}	equity vo	-0.02	0.14	0.00	0.22
t-value		-0.31	2.73	0.03	2.52
F-Stat		5.53	12.56	5.73	2.65
R^2		0.10	0.20	0.10	0.10
N		718	719	718	366

1. Trading revenues are standardized by the banks' respective trading revenue standard deviaitons. The coefficients for the market factors and equity volume measure the number of standard deviation changes in trading revenue for a 2 standard deviation change in the respective market factor and equity volume variables.

Table 6b. F-Statisitics for Market Factors and Chow Test

F-Statistics for Market Factors[1]

Sample Period: 1998 - 2000

	All Market Factors = 0		Exchange Factors =0		Equity Factors = 0	
Bank	F	F*(5%)	F	F*(5%)	F	F*(5%)
3	6.95	1.80	8.10	2.38	4.38	3.01
4	4.77	1.80	2.02	2.38	15.64	3.01
5	1.67	1.80	2.20	2.38	0.57	3.01
6	1.04	1.80	0.56	2.38	0.45	3.01

	Interest Factors = 0		Credit Factors = 0	
Bank	F	F*(5%)	F	F*(5%)
3	4.73	3.01	4.85	2.62
4	2.35	3.01	2.02	2.62
5	2.19	3.01	1.52	2.62
6	3.66	3.01	1.22	2.62

Sample Period: 2001 - 2003

	Market Factors = 0		Exchange Factors = 0		Equity Factors = 0	
Bank	F	F*(5%)	F	F*(5%)	F	F*(5%)
3	4.93	1.80	1.58	2.38	2.49	3.01
4	3.65	1.80	1.39	2.38	11.48	3.01
5	3.73	1.80	1.36	2.38	1.81	3.01
6	2.57	1.82	1.15	2.40	1.60	3.02

	Interest Rates = 0		Credit Spreads = 0	
Bank	F	F*(5%)	F	F*(5%)
3	19.30	3.01	8.10	2.62
4	3.45	3.01	1.38	2.62
5	11.61	3.01	2.09	2.62
6	2.72	3.02	4.02	2.63

1. F-values(n_1 = number of restrictions in each market categroy, n_2 = sample size - 15).

Chow Test for Differences in Market Factor Coefficients Between the Two Sample Periods

	Bank 3	Bank 4	Bank 5	Bank 6
F-Values (n_1= 11, n_2 = sample size - 26)	5.455	1.487	2.544	1.084
5% critical F value	1.795	1.795	1.795	1.795

Table 7. Bank Trading Revenue Volatility Conditioned on Low, High Market Volatility[1]

	Exchange Rate Volatility			
	Low	High	Low	High
Bank	Mean Revenue		Median Revenue	
1	1.13	1.28*	0.98	1.14*
2	0.96	1.09*	0.80	0.90
3	1.03	0.96	0.92	0.75
4	1.06	1.08	0.90	0.88
5	0.89	0.90	0.72	0.65
6	0.89	0.95	0.70	0.77
7	0.50	0.71*	0.36	0.49

	Interest Rate Conditioning			
	Low	High	Low	High
Bank	Mean Revenue		Median Revenue	
1	1.16	1.33*	1.05	1.17
2	0.94	1.23*	0.80	1.021*
3	0.92	1.12*	0.76	0.96*
4	0.98	1.13*	0.81	0.93*
5	0.80	0.97*	0.63	0.78*
6	0.86	0.96*	0.72	0.77
7	0.53	0.71*	0.45	0.42

	Equity Volatility			
	Low	High	Low	High
Bank	Mean Revenue		Median Revenue	
1	1.14	1.36*	1.04	1.17*
2	0.93	1.20*	0.79	0.98*
3	0.96	1.06*	0.76	0.90*
4	1.00	1.22*	0.84	0.92*
5	0.89	0.82	0.72	0.65
6	0.87	1.03*	0.74	0.83*
7	0.57	0.52	0.43	0.36

	Credit Spread Volatility			
	Low	High	Low	High
Bank	Mean Revenue		Median Revenue	
1	1.13	1.43*	1.00	1.23*
2	0.89	1.13*	0.77	0.91*
3	0.93	1.12*	0.79	0.93*
4	1.02	1.15*	0.83	0.93*
5	0.82	0.92*	0.63	0.70*
6	0.87	0.95	0.67	0.79*
7	0.63	0.63	0.46	0.44

1.Trading revenues are divided by bank's respective trading revenue standard deviations. The range of sample sizes for individual market categories, is 140 to 494, with a median of 337.

* significant at .05. Significance for the mean difference uses a standard diference of two means test. The medians test of significance uses the Mann-Whitney-Wilcoxon rank sum test for large samples.

Table 8. Bank VaR Conditioned on Low and High Market Volatility[1]

	Exchange Rate Volatility			
	Low	High	Low	High
Bank	Mean VaR		Median VaR	
1	1.92	1.98*	1.91	1.96
2	1.62	1.75*	1.58	1.80*
3	4.10	4.18	4.07	4.21
4	7.54	6.75	7.37	6.56
5	3.76	4.23*	3.09	3.62
6	2.20	1.96	2.05	1.88
7	2.56	2.82*	2.54	2.64

	Interest Rate Volatility			
	Low	High	Low	High
Bank	Mean VaR		Median VaR	
1	1.88	2.02*	1.89	1.99*
2	1.72	1.72	1.76	1.82
3	4.20	4.00	4.19	4.07
4	6.67	7.12*	6.50	7.20*
5	4.22	3.88	3.41	3.29
6	2.03	2.08	1.89	1.95
7	2.64	2.91*	2.58	2.67*

	Equity Volatility			
	Low	High	Low	High
Bank	Mean VaR		Median VaR	
1	1.90	1.98*	1.91	1.93*
2	1.77	1.59	1.88	1.50*
3	4.13	4.02	4.10	4.06
4	6.68	7.75*	6.22	7.65*
5	4.33	3.51	3.60	2.90
6	2.09	2.08	1.95	1.96
7	2.73	2.68	2.60	2.57

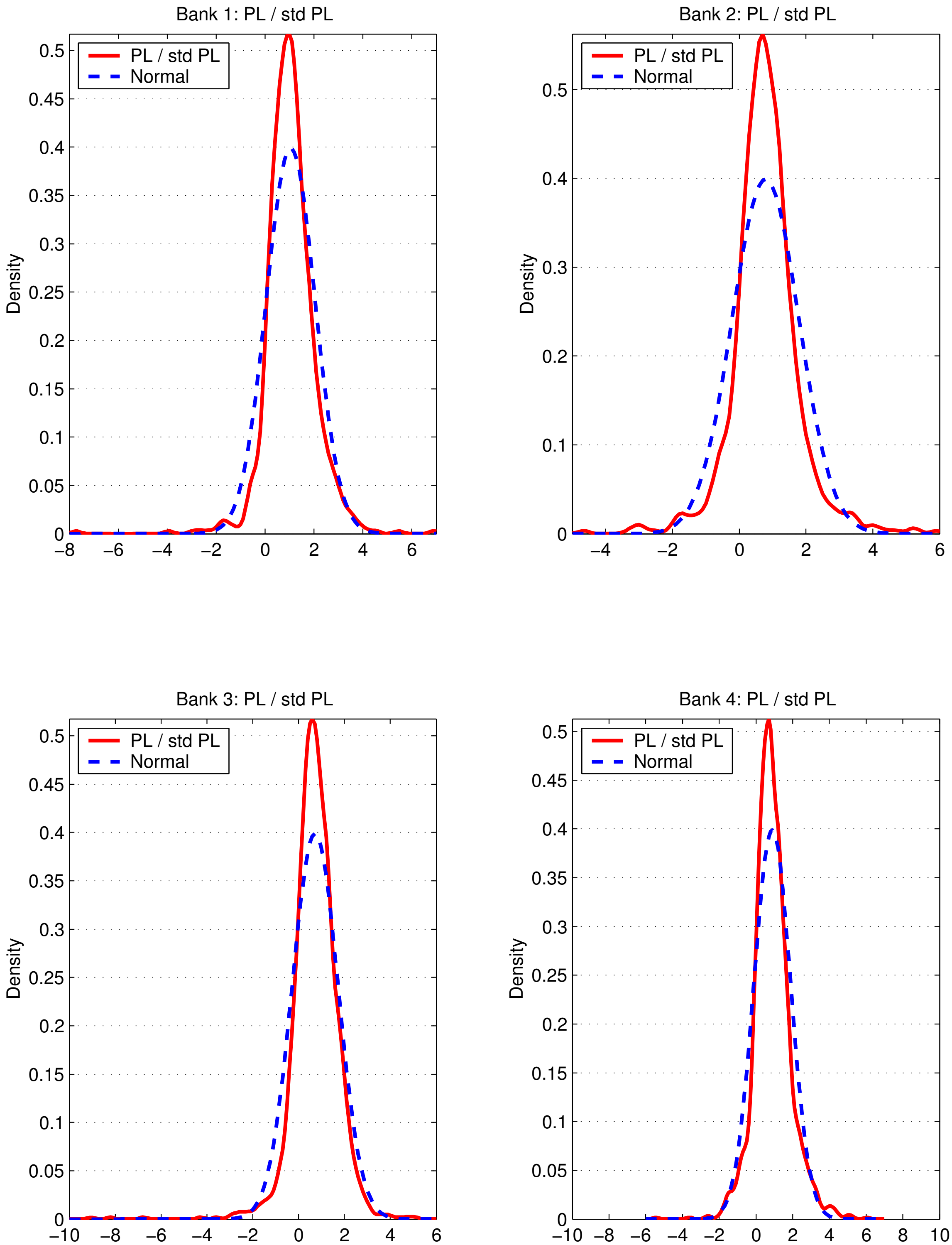
	Credit Spread Volatility			
	Low	High	Low	High
Bank	Mean VaR		Median VaR	
1	1.92	1.98	1.91	1.92
2	1.75	1.62	1.75	1.60
3	4.30	3.93	4.29	4.05
4	6.85	7.26*	6.63	7.30*
5	4.23	3.71	3.41	3.19
6	2.04	2.06	1.93	1.95
7	2.62	2.84*	2.59	2.61

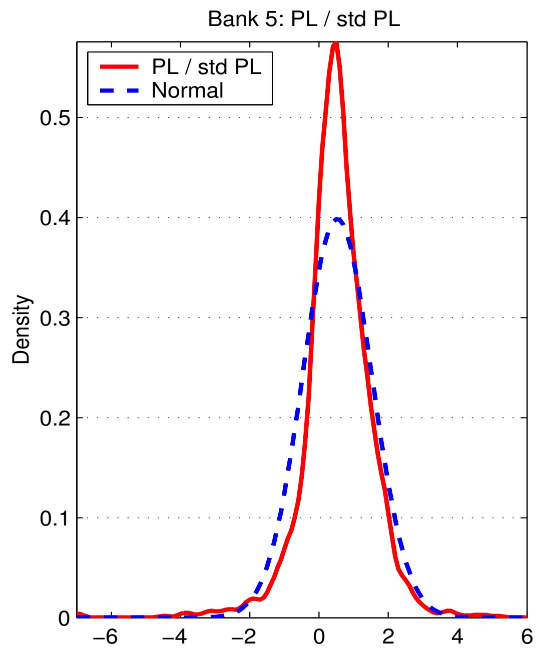
1. Bank trading revenue is normalized by the bank tradinge revenue standard deviaitions. Samples sizes for Low and High market volatility days range from 140 to 494. The absolute values for individual market factors in each of the 4 market categories are equal to .2 to .3 standard deviations for Low volatility days and 1 to 1.5 standard deviations for High market volatilty days.

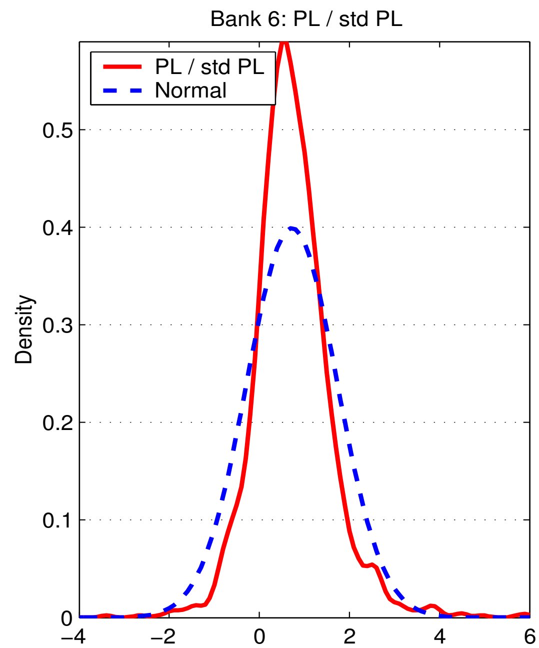
*Significance is measured at the .05 level. For the mean difference, a standard difference of two means test is used. The medians test uses the Mann-Whitney-Wilcoxon rank sum test for large samples.

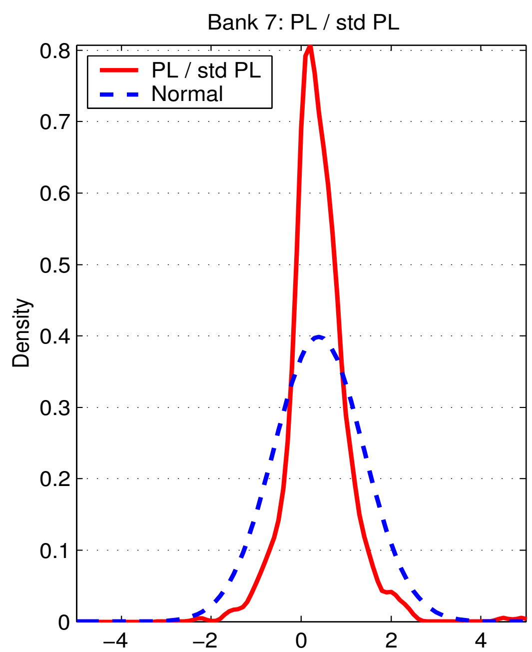
Figure 1. Kernel Densities of Bank Trading Revenue

(trading revenue standardized by trading revenue standard deviations)




Bank 5: PL / std PL
PL / std PL
Normal
Density
0.5
0.4
0.3
0.2
0.1
0
−6
−4
−2
0
2
4
6


Bank 6: PL / std PL
PL / std PL
Normal
Density
0.5
0.4
0.3
0.2
0.1
0
−4
−2
0
2
4
6


Bank 7: PL / std PL
PL / std PL
Normal
Density
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−4
−2
0
2
4