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Journal of Financial Intermediation 12 (2003) 277–297
Journal of Financial Intermediation
www.elsevier.com/locate/jfi

Bank foreign exchange and interest rate risk management: simultaneous versus separate hedging strategies

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Received 12 September 2002

Abstract

This paper investigates the hedge ratio dynamics for large US banks with exposure to both interest rate and foreign exchange risks. Using a mean–variance framework, the paper evaluates hedging performance when interest rate and foreign exchange risks are hedged *separately* versus *simultaneously*. Optimal hedge ratios for separate and simultaneous hedging strategies are estimated using the multivariate GARCH model. The magnitude of separate hedge ratios is found to consistently overstate that of simultaneous hedge ratios for banks that engage in both domestic loan extensions and foreign exchange operations. Both in-sample and out-of-sample results indicate that a simultaneous hedging strategy outperforms a separate hedging strategy. The mean–variance efficiency test results strongly support statistical significance to this finding.

JEL classification: G21

Keywords: Separate hedging; Simultaneous hedging; Interest rate risk; Foreign exchange risk

1. Introduction

A number of large US banks have been actively engaging in foreign exchange operations in order to offer a more competitive service to a growing customer base in foreign markets

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1042-9573/$ – see front matter
doi:10.1016/S1042-9573(03)00039-1

and to take advantage of the profit opportunities perceived in fluctuating foreign exchange rates. Yet, with the expansion of international financial relationships and the continued liberalization of cross-border cash flows, the banks have become more and more exposed to the risks associated with foreign exchange operations as well as funding costs both at home and abroad. Financial exposure of banks that engage in both domestic banking activity and foreign exchange operations can be separated into two primary categories: interest rate exposure and foreign exchange exposure. Such exposure can have a significant impact on a bank's financial performance.

The forward and futures markets have provided the US banks, among others, with a vehicle for hedging against unanticipated changes in foreign exchange and interest rates (see Chamberlain et al., 1997; Brewer III et al., 2000; and Allayannis and Ofek, 2001). Numerous studies have examined in great detail the issue of hedging interest rate risk using interest rate futures contracts and hedging foreign exchange risk using currency forward/futures contracts in a separate framework (see Koppenhaver, 1985; Morgan et al., 1988; Carter and Sinkey, 1998; Sercu and Wu, 2000; Allayannis and Ofek, 2001). The extant hedging models, therefore, almost universally fail to provide an examination of the simultaneous relationship between the two hedging methods.

As acknowledged by Choi and Elyasiani (1997) and Santomero (1997), there needs to be a simultaneous framework for interest rate and foreign exchange risk management in order to correctly understand the bank's market risk.[1] Banking activities such as the acceptance of deposits, extension of loans, and foreign exchange operations are simultaneously interrelated to one another over a given period of time through foreign exchange and interest rates (both domestic and foreign). For example, the interest rate of a given currency will be influenced by interest rate developments of other currencies and financial markets' expectations on future foreign exchange rates of the currencies. The interdependence of these variables makes it necessary that bank managers have a broad spectrum of understanding in managing the bank's market risk. In order for the bank management to implement an effective hedging strategy for funding costs and foreign exchange operations, the relationship between futures and forward returns as well as their relationships to returns from loan extensions and foreign exchange operations should be concurrently investigated as a portfolio problem.[2] A simultaneous analysis of multiple risks within the context of portfolio problems is well addressed in Schrand and Unal (1998) and Meulbroek (2002) Although dealing with a different array of risk sources and institutions from this paper, they highlight the importance of simultaneous risk management when multiple risks are bundled together.

[1] Although the concept of simultaneous management of interest rate and foreign exchange risks can be applied to any firm including non-financial firm, the need for simultaneous risk management using futures/forward contracts is especially important for large banking firms. This is because derivative holdings are concentrated at large banks and large banks more frequently trade these derivatives to hedge interest rate and foreign exchange risks (see Houpt, 1999).

[2] In recent years, simultaneous risk management pioneered by Bankers Trust has been receiving increased attention. Yet, bank managers do not view risk management as a portfolio problem. As Santomero (1997, p. 112) states, "Rather, they separately evaluate each risk and aggregate total exposure by simple addition. As a result, much is lost in the aggregation. Perhaps over time this issue will be addressed." This situation provides a large amount of room for improving banks' risk-management practices.

The question that naturally arises is whether the banking firm with exposure to both interest rate and foreign exchange risks can improve its risk-return performance by hedging the two sources of risks simultaneously relative to hedging them separately. A systematic analysis of this question, to our knowledge, does not exist in the literature. We address this question by developing a theoretical hedging model that accommodates both risks, and evaluating hedging performance for the US banking system[3] when interest rate and foreign exchange risks are hedged separately versus simultaneously.

To parsimoniously accomplish our objective, we employ an optimal hedging model of the banking firm and develop a unified framework for bank hedging within the context of the portfolio problem by integrating two strands of the literature on hedging: studies on hedging behavior under domestic interest rate uncertainty with interest rate futures contracts (Koppenhaver, 1985; Morgan et al., 1988; Hirtle, 1997; Carter and Sinkey, 1998; Brewer III et al., 2000) and studies on hedging behavior under foreign exchange rate uncertainty with currency futures/forward contracts (Kirkvliet and Moffett, 1991; Baillie and Myers, 1991; Kroner and Sultan, 1993; Geczy et al., 1997; Sercu and Wu, 2000; Allayannis and Ofek, 2001). Performance evaluation for our unified approach is conducted within a mean-variance framework using hedge ratios estimated over time using a multivariate generalized autoregressive conditional heteroskedastic (GARCH) model. Multivariate GARCH models have been successfully applied in the estimation of dynamic (time-varying) hedge ratios in the futures/forward market (see, for example, Cecchetti et al., 1988; Baillie and Myers, 1991; Kroner and Sultan, 1993; Tong, 1996; Koutmos and Pericli, 1998) and is often suggested as an enhancement to bank hedging techniques (see Santomero, 1997). Statistical significance of hedging performance is examined using GMM-based efficiency tests. The empirical evidence in this paper demonstrates that a strategy that considers both interest rate and foreign exchange risks simultaneously can uniformly improve performance relative to a strategy that considers hedging the two sources of risks separately.

The paper is organized as follows. Section 2 derives hedge ratios for which interest rate and foreign exchange risk are hedged separately or simultaneously. Section 3 provides empirical analysis including the estimation of dynamic hedge ratios, and comparisons and statistical significance of hedging performance. Finally, conclusions are given in Section 4.

2. The model

We take a two-period perspective for banks that engage in both domestic banking activity and foreign exchange operations. At the current time period, the bank receives short-term deposits, makes longer-term fixed rate loans, and enters a net asset (or liability) position in foreign currency. Also, bank managers make decisions with regard to positions in interest rate futures and foreign exchange forward contracts, anticipating that the bank will not only borrow short-term funds (e.g., Eurodollar or negotiable certificate of

[3] Since individual bank data were not available with sufficient detail, we employed aggregate data for the US banking system representing the ‘average’ US commercial bank’s hypothetical portfolio composed of domestic loans and deposits, and a benchmark foreign exchange portfolio.

deposits) at an unknown random rate but also liquidate the net position in foreign currency at an unknown foreign exchange rate at a later time period.

Short-term deposit borrowing (and refinancing later at a random rate) to fund longer term loans at a fixed rate creates a mismatch in maturity, i.e., interest rate risk. Taking a net position in foreign currency at a known foreign exchange rate and liquidating it at an unknown rate at a later time period creates a foreign exchange risk. Our model, therefore, explicitly takes into consideration both interest rate and foreign exchange risks. Facing interest rate and foreign exchange risks simultaneously, the bank, at the start of the current period, establishes both interest rate futures and foreign exchange forward contracts for deliveries of short-term funds and foreign currencies at a later time period.

Before proceeding with the analysis, we provide an index of definitions of main variables that will be used throughout the paper.

- L — the fixed dollar amount of long-term loans demanded at the start of the current period.
- C — the net position (expressed in units of foreign currency) in foreign currency assets.
- S, S_{T} — the spot foreign exchange rate (expressed in units of US dollar per one unit of foreign currency) at the start of the current period and at the end of the terminal period, respectively.
- D — the level of US dollar denominated deposits (CDs) received by the bank.
- R_{L} — the long-term fixed loan rate.
- R_{D} — the geometric average of deposit rates prevailing at the current and terminal period.
- R^* — the geometric average of foreign interest rates prevailing at the current and terminal period.
- f, f_{T} — the rate for interest rate futures contract at the start of the current period and at the terminal period, respectively.
- F, F_{T} — the forward exchange rate at the start of the current period and at the end of the terminal period, respectively.
- N_f — the quantity of interest rate futures contracts that the bank establishes at the start of the current period. This is a decision variable and $N_f > 0$ corresponds to a long position and $N_f < 0$ corresponds to a short position.
- N_F — the quantity of forward exchange contracts that the bank establishes at the start of the current period. This is a decision variable and $N_F > 0$ corresponds to a long position and $N_F < 0$ corresponds to a short position.

Profits are obtained from the interest payment on loans plus a return from holding foreign currencies less the costs of deposits. The return from a foreign currency investment is the interest rate for the currency and period considered plus any exchange rate variation (see Levy, 1981, and Grammatikos et al., 1986). It then follows that the profit function can be written as

$$\pi = LR_{\mathrm{L}} - DR_{\mathrm{D}} + \sum_{i=1}^{n} C_i\big[\big(1 + R_i^*\big)S_{i,\mathrm{T}} - S_i\big], \tag{1}$$

where i indexes various currencies.

To further develop the profit function, we assume that the following covered interest rate parity (CIRP) condition holds in each currency:[4]

$$\frac{1+R_\mathrm{D}}{1+R_i^*}=\frac{F_i}{S_i}. \tag{2}$$

A balance sheet constraint is set to be $L+\sum_{i=1}^{n} C_i S_i = D$ at the start of the current period, so that normal bank operations such as domestic loan extensions and foreign exchange operations are funded by bank deposits.[5] Substituting this constraint and Eq. (2) simultaneously into Eq. (1), we obtain

$$\pi = L(R_\mathrm{L}-R_\mathrm{D})+\sum_{i=1}^{n} C_i\bigl(1+R_i^*\bigr)(S_{i,\mathrm{T}}-F_i). \tag{3}$$

Equation (3) indicates that the bank's profit function, incorporating the constraint, is composed of the net interest revenue (net of stochastic deposit costs) from domestic loan extensions and the stochastic return from foreign exchange operations. Allowing the stochastic bank profit to be hedged by entering interest rate futures and/or foreign exchange forward contracts, the overall profit function can be augmented to include the profit (or loss) from futures and forward transaction, i.e., $N_f(f_\mathrm{T}-f)$ and/or $N_F(F_\mathrm{T}-F)$. When the bank hedges interest rate risks using only interest rate futures or hedges foreign exchange risks of a particular currency one at a time using only the corresponding forward contract, thus separating the management of interest rate risks from foreign exchange risks, we term this "separate hedging strategy." The profit function in each case becomes[6]

$$\pi = L(R_\mathrm{L}-R_\mathrm{D})+N_f(f_\mathrm{T}-f) \quad \text{for hedging interest risk separately,} \tag{4a}$$

or

$$\pi = C\bigl(1+R^*\bigr)(S_\mathrm{T}-F)+N_F(F_\mathrm{T}-F) \quad \text{for hedging exchange risk separately.} \tag{4b}$$

Bank management selects its optimal holdings of interest rate futures or foreign exchange forward contracts at each time by maximizing the expected utility function defined over profit and described by a time-varying hedging behavior within the mean–variance framework,

$$\underset{N_{f,t},N_{F,t}}{\mathrm{Max}}\; E_t\bigl[U(\pi_{t+1})\bigr]=E_t(\pi_{t+1})-\frac{1}{2}\chi\sigma_t^2(\pi_{t+1}), \tag{5}$$

[4] The validity of the CIRP relationship is upheld by various empirical studies (see, for example, Frenkel and Levich, 1975; Clinton, 1988; Fletcher and Taylor, 1994) and is adamantly asserted by managers of large financial institutions.

[5] This constraint implicitly assumes that bank capital supplies the funds necessary to acquire and maintain fixed assets and intangible assets.

[6] This model assumes no transaction costs associated with establishing, maintaining, and rolling over the hedging program. For larger banking firms that have scale economies in hedging, the transaction costs will be relatively minor. This may make hedging through futures/forwards relatively more attractive to larger banks that want to lock in a long-term hedge. Equation (4a) is similar to Koppenhaver (1985), and Morgan et al. (1988).

where χ is the risk aversion parameter, and the expectation and variance operators are subscripted with t to indicate that they are measured conditional on information available at time t.[7]

It is quite natural that bank management changes its hedge ratios as new information arrives to the market. That is, hedge ratios vary with time as the conditional moments of return variables change. Under the assumption of *martingale* futures markets, expected utility-maximizing hedge ratios for separate hedging of domestic loan extensions and foreign exchange operations at time t can be, respectively, obtained as[8]

$$\beta^*_{f,t} = -\frac{\mathrm{Cov}_t[(R_{\mathrm{L},t} - R_{\mathrm{D},t}), (f_{t+1} - f_t)]}{\mathrm{Var}_t(f_{t+1} - f_t)}, \tag{6a}$$

$$\beta^*_{F,t} = -\frac{\mathrm{Cov}_t[(1 + R^*_t)(S_{t+1} - F_t), (F_{t+1} - F_t)]}{\mathrm{Var}_t(F_{t+1} - F_t)}. \tag{6b}$$

Equations (6a) and (6b) indicate that the optimal risk-minimizing hedge is determined by conditional covariances between the returns from loan extensions and interest rate futures transaction, conditional covariances between the returns from foreign exchange spot and forward transaction, and conditional variances of the return from futures or forward transaction. Optimal hedge ratios can be statistically estimated by running a regression that determines the mean and variance used for performance evaluation of hedging. The regression method is presented in detail in following sections.

In contrast with the simple separation approach described above, a large number of US banks simultaneously extend loans, trade foreign exchanges, and transact both interest rate futures and foreign exchange forward for hedging purposes for a given period of time. These banking activities can be adequately factored into the model by investigating the relationship between futures and forward returns as well as their relationships to returns from loan extensions and foreign exchange operations.

As seen in Table 1, returns from loan extensions and foreign exchange operations are negatively (although not highly) correlated and so are the returns from interest rate futures

[7] Mean–variance expected utility maximization appropriately reflects the concerns of the typical bank with total risk and the relevance for bank owners and managers of strategies for reducing total risk. In practice, banks can be characterized as insufficiently diversified due to specialization, regulatory restrictions, and asset-transformation rents as well as intrafirm incentive problems (see Millon and Thakor, 1985, and Bhattacharya and Thakor, 1993) and thus can not avoid idiosyncratic risk. Although bank owners may be able to diversify this risk away, bank regulators are still concerned with the total risk in an individual bank due to potential link between bank failures and economic growth and will thus impose restrictions on bank managers that depend on this risk. Consequently, bank managers will be concerned with total risk. The mean–variance specification parsimoniously represents such concerns with total portfolio variance in conjunction with the expected payoffs. Also, the threat of loss of the bank's charter value due to failure/regulatory closure and the costs of distress that precedes closure could induce a concavity in the bank's objective function and lead to mean–variance optimization (see Bhattacharya and Thakor, 1993).

[8] It can be shown that the expected utility-maximizing hedge ratio under the assumption of martingale futures markets is also the minimum variance hedge ratio. Statistical evidence presented in a later part of this paper shows that expected returns to holding futures/forward contracts conditional on information available at time t are not statistically different from zero, supporting that the expected utility-maximizing hedging rule is consistent with variance minimization. The martingale assumption is widely employed in empirical hedge ratio literature (see, for example, McCurdy and Morgan, 1988; Baillie and Myers, 1991; Kroner and Sultan, 1993).

Table 1
Correlation matrix and summary statistics
A. Correlation and summary statistics of log returns on spot and futures/forward

		$R_L - R_D$	$(1+R^*)(S_T - F)$			
			BP	DM	JY	SF
$R_L - R_D$		1.0000	−0.1348	−0.1487	−0.1836	−0.1579
$f_T - f$		−0.2361	−0.1396	−0.1030	−0.2205	−0.1151
$F_T - F$:	BP	−0.0380	0.3865	0.2031	0.0950	0.2158
	DM	−0.0694	0.1893	0.4140	0.1839	0.2855
	JY	−0.0432	0.0661	0.1199	0.2766	0.1695
	SF	−0.0326	0.1995	0.3109	0.2528	0.4133
Mean[a] (%)		10.043	3.0826	0.8410	−2.739	−0.249
St. dev. (%)		4.302	2.915	2.891	3.516	3.256
ADF statistic[b]		−6.16(1)	−7.41(2)	−7.29(0)	−7.20(1)	−7.30(0)

B. Correlation and summary statistics of log returns on Eurodollar futures and foreign exchange forward contracts

	$f_T - f$	$F_T - F$			
		BP	DM	JY	SF
$f_T - f$	1.0000	−0.1781	−0.2821	−0.1604	−0.2798
Mean[a] (%)	−0.1487	−0.1787	0.3023	0.2775	0.4680
St. dev. (%)	0.2967	2.5849	2.5935	3.5069	2.9506
ADF statistic[b]	−7.41(1)	−7.84(1)	−7.75(0)	−9.19(1)	−7.81(0)

[a] The mean value is annualized.
[b] Critical values of the augmented Dickey–Fuller (ADF) are −2.88 and −3.46 at 5% and 1% significance level, respectively. The numbers in parentheses are the lag lengths that were optimally chosen for the ADF regression.

and foreign exchange forward transactions.[9] Those relationships among return variables are interesting factors to examine in the context of bank management's hedging decisions. We consider the case where the bank hedges both loan extensions and foreign exchange operations simultaneously using both interest rate futures and foreign exchange forwards, thereby coordinating the array of two sources of risk as a portfolio problem. We term this "simultaneous hedging strategy." Expected utility-maximizing hedge ratios under the simultaneous hedging strategy at time t can be shown to take the form:

$$\beta_t^{**} = -\left[\,\Sigma_t^{-1}\Sigma_{f,t} \quad \Sigma_t^{-1}\Sigma_{F,t}\,\right] = -\begin{pmatrix} \beta_{11,t}^{**} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t}^{**} \end{pmatrix}, \tag{7}$$

where

$$\Sigma_t = \begin{pmatrix} \Sigma_{00,t} & \Sigma_{01,t} \\ \Sigma_{10,t} & \Sigma_{11,t} \end{pmatrix}, \qquad \Sigma_{f,t} = \begin{pmatrix} \Sigma_{df,t} \\ \Sigma_{dF,t} \end{pmatrix}, \qquad \Sigma_{F,t} = \begin{pmatrix} \Sigma_{sf,t} \\ \Sigma_{sF,t} \end{pmatrix},$$

$$\beta_{11,t}^{**} = (\det \Sigma_t)^{-1}(\Sigma_{11,t}\Sigma_{df,t} - \Sigma_{01,t}\Sigma_{dF,t}),$$

$$\beta_{12,t} = (\det \Sigma_t)^{-1}(\Sigma_{11,t}\Sigma_{sf,t} - \Sigma_{01,t}\Sigma_{sF,t}),$$

[9] Positive correlations would not alter the main results regarding the benefit to simultaneous hedging strategy discussed in the following section but would change long to short and short to long in the optimal positions. As long as a non-zero correlation exists, benefits to simultaneous hedging will exist.

$$\beta_{21,t} = (\det \Sigma_t)^{-1}(\Sigma_{00,t}\Sigma_{dF,t} - \Sigma_{10,t}\Sigma_{df,t}),$$
$$\beta^{**}_{22,t} = (\det \Sigma_t)^{-1}(\Sigma_{00,t}\Sigma_{sF,t} - \Sigma_{10,t}\Sigma_{sf,t}).$$

Here Σ_t is the 2×2 conditional variance–covariance matrix of futures and forward returns at time t, which is symmetric and positive definite; $\Sigma_{d(s)f,t}$ is the conditional covariance between the return from loan extensions (foreign exchange rate operations) and the return from interest rate futures transaction; $\Sigma_{d(s)F,t}$ is the conditional covariance between the return from loan extensions (foreign exchange rate operations) and the return from foreign exchange forward transaction; $\beta^{**}_{11,t}$ and $\beta^{**}_{22,t}$ determine optimal hedge ratios for the interest rate and foreign exchange risk, respectively. This representation for optimal hedge ratios allows us to correctly reflect the correlation between interest rate futures and foreign exchange forward returns as well as their correlation to returns from spot operations.

A comparison of performance between the separate and simultaneous hedging strategies is made within a mean–variance framework using the optimal hedge ratios obtained from Eqs. (6) and (7). To do this, we construct a portfolio that has foreign currency positions equally weighted among the currencies of denomination.[10] Then, the portfolio return at time $t + 1$ can be obtained as

$$R_{t+1} = \omega_t(R_{\mathrm{L},t} - R_{\mathrm{D},t}) + \frac{(1-\omega_t)}{n}\sum_{i=1}^{n}\bigl(1 + R^{*}_{i,t}\bigr)\left(\frac{S_{i,t+1} - F_{i,t}}{S_{i,t}}\right), \tag{8}$$

where $\omega_t = L_t/D_t$ and n is the number of positions in foreign currencies. The overall portfolio return (including off-balance-sheet activities), R^{P}_{t+1}, can be written in matrix form as

$$R^{\mathrm{P}}_{t+1} = R_{t+1} + (\mathbf{B}_t)'\mathbf{G}_{t+1}, \tag{9}$$

where $\mathbf{B}_t$ is the $N \times 1$ hedge ratio vector at time t with N the number of hedging instruments, and $\mathbf{G}_{t+1}$ the $N \times 1$ vector of returns from futures/forward transactions at time $t+1$. Expected returns and variances that are used as the criteria of performance evaluation are measured by taking expected value and variance for Eq. (9).

3. Empirical analysis

3.1. Data

The sampling interval of the data is monthly (beginning January 1991 and ending December 2000) and we assume that the hedge is constructed at the start of the month, using three-month contracts, and its performance is evaluated at the end of month. Then, a new

[10] It is often suggested that a value-weighted currency portfolio tends to capture no exchange exposure in exchange rate models (see Bodnar and Wong, 2000, and Dominguez and Tesar, 2001). In practice, the performance that currency managers generate from positioning foreign currencies is measured against a benchmark equally weighted currency portfolio, as opposed to value-weighted, in order to preclude managers from biasing their positions toward highly value-weighted currencies.

hedge is constructed using new three-month contracts with periodic reevaluation.[11] The spot, forward, and futures rates are collected for foreign currencies: the British pound (BP), German mark (DM), Japanese yen (JY), and Swiss franc (SF), all relative to the US dollar. A series of these rates are collected from the Data Resources Incorporated (DRI) data base. Assuming that banks use 90-day foreign exchange forward contracts, an interest rate futures position is established with contracts that expire in three or longer months but not exceeding six months. Eurodollar futures that are heavily used by commercial banks in the US are used as a proxy for interest rate futures. Prime rates charged by banks are used as a proxy for loan rates, three-month CD rates for deposit rates.[12] These data plus foreign short-term (3-month) interest rates, and position of the US commercial banking system's loans and deposits are collected from the *Federal Reserve Bulletin*.

3.2. Estimation of optimal hedge ratios by multivariate GARCH models

In this section, we estimate the optimal hedge ratios for loan extensions and foreign exchange operations under separate and simultaneous hedging for a hypothetical bank that mimics the US banking system. The dynamic (time-varying) optimal hedge ratios are obtained using a multivariate generalized autoregressive conditional heteroskedasticity (GARCH) model which permits conditional variances and covariances to change with time. As seen in Table 2, tests for residual GARCH effects using both Ljung-Box $Q^2(24)$ statistic and likelihood ratio (LR) test of the null: $\mathbf{A} = \mathbf{B} = \mathbf{0}$ for model (10c) described below strongly supports the time-varying variance of disturbances.

The multivariate GARCH model is widely applied to a hedging strategy where hedge ratios vary over time (see for example, Cecchetti et al., 1988; Baillie and Myers, 1991; Kroner and Claessens, 1991; Kroner and Sultan, 1993; Tong, 1996; Koutmos and Pericli, 1998) and is often suggested as an enhancement to bank hedging techniques (see Santomero, 1997). The format of a multivariate GARCH model has a positive definite parameterization to ensure that the covariance matrix of residuals is positive definite:

$$\mathbf{y}_t = \mu + \mathbf{e}_t, \tag{10a}$$

$$\mathbf{e}_t \mid \Omega_{t-1} \sim N(0, \mathbf{H}_t), \tag{10b}$$

$$\mathbf{H}_t = \mathbf{C}'\mathbf{C} + \mathbf{A}'\mathbf{e}_{t-1}\mathbf{e}'_{t-1}\mathbf{A} + \mathbf{B}'\mathbf{H}_{t-1}\mathbf{B}, \tag{10c}$$

where $\mathbf{y}_t$ is the $n \times 1$ vector containing the bank's spot and futures/forward returns; μ is the $n \times 1$ vector of constants; $\mathbf{e}_t$ is the $n \times 1$ vector of disturbances; Ω_{t-1} is the information set available at time $t-1$; $\mathbf{H}_t$ is the $n \times n$ time-dependent conditional covariance matrix; and $\mathbf{C}, \mathbf{A}$, and $\mathbf{B}$ are the $n \times n$ parameter matrices. To obtain dynamic hedge ratios for the separate hedging strategy ($n = 2$), we define $\mathbf{y}_t$ as either a 2×1 vector of $[(R_{\mathrm{L},t} - R_{\mathrm{D},t}), (f_{t+1} - f_t)]'$ for the interest rate risk hedging, or a 2×1 vector of

[11] As a practical matter, large US banks usually measure interest rate risks on a weekly or monthly basis (see Santomero, 1997).

[12] In practice, many loans are made at rates below the prime rate. Nonetheless, the prime rate is a benchmark indicator of the level of loan rates.

Table 2
Tests of GARCH effects
A. Separate hedging strategy

	Eurodollar futures	Foreign exchange forward			
		BP	DM	JY	SF
LR test: $\mathbf{A}=\mathbf{B}=\mathbf{0}$[a]	87.18	247.11	34.94	71.08	24.58
$Q^2(24)$: spot	27.17	28.92	24.62	28.57	21.55
$Q^2(24)$: futures or forward	19.39	16.58	18.09	16.38	16.92

B. Simultaneous hedging strategy

	Eurodollar futures + foreign exchange forward			
	+BP	+DM	+JY	+SF
LR test: $\mathbf{A}=\mathbf{B}=\mathbf{0}$[b]	328.30	355.91	169.97	149.51
$Q^2(24)$: spot1[c]	28.73	29.65	28.75	28.61
$Q^2(24)$: spot2[c]	21.94	27.87	28.60	23.43
$Q^2(24)$: futures	19.65	19.59	19.61	19.71
$Q^2(24)$: forward	24.38	25.68	29.87	24.22

Note: $Q^2(24)$ is a Ljung–Box statistic for residual GARCH effects in the squared standardized residuals. $Q^2(24)$ is distributed $\chi^2_{(24)}$ and has 95% critical value 36.42.

[a] The likelihood ratio test statistic for the null of $A=B=0$ is $\chi^2_{(8)}$ that has 95% critical value 15.51.

[b] The likelihood ratio test statistic for the null of $A=B=0$ is $\chi^2_{(32)}$.

[c] Spot1 and spot2 signify the return from loan extensions and from foreign exchange operations, respectively.

$[(1+R_t^*)(S_{t+1}-F_t), (F_{t+1}-F_t)]'$ for the foreign exchange risk hedging. To obtain dynamic hedge ratios for the simultaneous hedging strategy ($n=4$), we define $\mathbf{y}_t$ as a 4×1 vector of $[(R_{\mathrm{L}t}-R_{\mathrm{D}t}), (1+R_t^*)(S_{t+1}-F_t), (f_{t+1}-f_t), (F_{t+1}-F_t)]'$. Since it is reasonable to base statistical inference on the change in the logarithm of foreign exchange rates, each exchange rate is measured as a logarithmic value (i.e., continuous rates of return). Similarly, interest rates are also measured as the logarithmic value of one plus the interest rate to produce continuously-compounded interest rates.

We conduct preliminary diagnostic checks on the multivariate GARCH models. First, tests for unit roots are conducted for each of the return series using augmented Dickey–Fuller (ADF) tests. As reported in Table 1, the presence of unit roots is strongly rejected for all of the return series, indicating that each of the return series is stationary. With the stationary return series, we can use the sample mean, variance, and autocorrelations to estimate the parameters of the actual data-generating process.

The parameter estimates and diagnostics for model (10) are reported in Table 3. The constant terms $\hat{\mu}_1$ in panel A capture expected returns to holding spot contracts. For example, $\hat{\mu}_1$ is 0.02653, meaning that the average quarterly (3-month) return on loan extensions is about 2.653% in the absence of any foreign exchange operation. The corresponding average returns in the presence of foreign exchange operations (including foreign exchange forward transaction) are shown in panel B to be 2.677% with BP, 2.698% with DM, 2.671% with JY, and 2.693% with SF. Thus, average returns to loan extensions in the presence of foreign exchange operations (including foreign exchange forwards transaction) rise for all currencies of denomination. Any estimate of $\hat{\mu}_2$ in panel A ($\hat{\mu}_2$ and $\hat{\mu}_4$

Table 3
Estimation of the multivariate GARCH models
A. Estimation for separate hedging strategy ($n = 2$)

	Eurodollar futures	Foreign exchange forward			
		BP	DM	JY	SF
$\hat{\mu}_1$	0.02653	0.00498	0.00354	−0.01557	0.00324
	(9.27)**	(2.82)**	(2.71)**	(−3.61)**	(1.53)
$\hat{\mu}_2$	−0.00077	0.00071	0.001983	−0.01114	0.00487
	(−1.59)	(0.66)	(1.36)	(−1.09)	(0.95)
$\widehat{C}_{11}$	0.00063	0.01560	0.02417	0.03284	0.02584
	(1.45)	(1.59)	(2.08)*	(1.60)	(1.47)
$\widehat{C}_{12}$	−0.00108	−0.00296	−0.00312	−0.00288	−0.00281
	(−0.98)	(−1.04)	(−0.28)	(−0.04)	(−0.35)
$\widehat{C}_{22}$	0.00180	0.00000	−0.00000	−0.00003	−0.00000
	(2.87)**	(0.00)	(−0.00)	(−0.00)	(−0.00)
$\hat{A}_{11}$	0.03909	0.25436	0.28122	0.07909	0.45447
	(0.15)	(2.15)*	(3.18)**	(2.01)*	(4.44)**
$\hat{A}_{12}$	0.26199	0.16879	0.17760	0.39376	−0.19356
	(2.63)**	(2.17)*	(0.33)	(2.19)*	(−0.30)
$\hat{A}_{21}$	0.03237	−1.02660	−0.20761	0.06493	0.06781
	(0.06)	(−4.60)**	(−0.26)	(2.03)*	(2.09)*
$\hat{A}_{22}$	0.20903	0.08994	0.06509	0.03660	0.10682
	(1.98)*	(0.72)	(2.19)*	(0.05)	(1.98)*
$\widehat{B}_{11}$	1.05044	0.37682	0.41265	0.35981	0.42110
	(6.09)**	(3.59)**	(2.63)**	(3.90)**	(2.69)**
$\widehat{B}_{12}$	0.79805	0.80369	0.86628	0.63550	0.87902
	(1.97)*	(5.15)**	(4.39)**	(5.21)**	(4.40)**
$\widehat{B}_{21}$	−0.09915	−0.28443	−0.23489	−0.23104	−0.33272
	(−1.38)	(−1.72)	(−1.25)	(−1.40)	(−2.16)*
$\widehat{B}_{22}$	0.43896	0.02277	0.049697	0.83706	0.00114
	(3.24)**	(0.24)	(0.45)	(5.95)**	(0.01)
Log likelihood[a]	−1306.85	−805.27	−773.04	−686.99	−747.35
LR test: $A = B = 0$	87.18	247.11	34.94	71.08	24.58
$Q(24)$: spot	32.62	29.65	29.17	30.37	29.02
$Q(24)$: futures	24.63	28.57	34.15	18.30	34.51
$Q^2(24)$: spot	27.17	28.92	24.62	28.57	21.55
$Q^2(24)$: futures	19.39	16.58	18.09	16.38	16.92

B. Estimation for simultaneous hedging strategy ($n = 4$)

	Eurodollar futures + foreign exchange forward			
	+BP	+DM	+JY	+SF
$\hat{\mu}_1$	0.02677	0.02698	0.02671	0.02693
	(19.91)**	(13.17)**	(18.32)**	(16.98)**
$\hat{\mu}_2$	−0.00048	−0.00055	−0.00052	−0.00043
	(−1.11)	(−1.46)	(−1.46)	(−0.98)
$\hat{\mu}_3$	0.00396	−0.00362	−0.00727	−0.00166
	(2.01)*	(−1.36)	(−2.17)*	(−1.69)
$\hat{\mu}_4$	0.00060	−0.00423	0.00092	0.00253
	(0.38)	(−1.69)	(0.24)	(1.17)

(*continued on next page*)

Table 3 (*continued*)

	Eurodollar futures + foreign exchange forward			
	+BP	+DM	+JY	+SF
$\hat{A}_{11}$	0.11000	0.07777	0.03416	0.08324
	(2.13)*	(0.61)	(0.13)	(2.73)**
$\hat{A}_{12}$	−0.23355	0.16809	−0.19927	−0.24553
	(−1.07)	(1.69)	(−0.47)	(−1.87)
$\hat{A}_{13}$	−0.00914	−0.17149	−0.37412	−0.23601
	(−0.01)	(−2.09)*	(−2.61)**	(−0.07)
$\hat{A}_{14}$	−0.80048	−0.17446	−0.05800	0.13432
	(−1.98)*	(−0.19)	(−0.02)	(0.16)
$\hat{A}_{21}$	0.08245	−0.03032	0.08606	0.12069
	(0.32)	(−0.11)	(0.18)	(2.30)*
$\hat{A}_{22}$	0.27695	0.36348	0.52342	0.20249
	(1.55)	(0.61)	(2.65)**	(1.40)
$\hat{A}_{23}$	−0.12960	−1.50033	0.01661	−0.02250
	(−2.05)*	(−0.34)	(0.01)	(−0.10)
$\hat{A}_{24}$	0.86247	−0.19687	−0.0598	0.03020
	(1.70)	(−2.10)*	(−0.01)	(1.01)
$\hat{A}_{31}$	−0.00817	−0.01024	0.01297	−0.01500
	(−0.36)	(−0.34)	(0.11)	(−0.76)
$\hat{A}_{32}$	0.02592	−0.05612	0.01820	−0.04432
	(0.47)	(−0.68)	(0.10)	(−2.74)**
$\hat{A}_{33}$	0.22170	0.00248	0.03209	0.00258
	(0.58)	(0.03)	(0.01)	(0.03)
$\hat{A}_{34}$	0.13320	0.09483	−0.03092	0.17106
	(2.17)*	(0.38)	(−0.02)	(2.06)*
$\hat{A}_{41}$	−0.02685	−0.02005	−0.00600	−0.00825
	(−1.04)	(−2.02)*	(−0.09)	(−0.40)
$\hat{A}_{42}$	−0.02090	0.01861	−0.01985	−0.02215
	(−0.47)	(0.35)	(−2.21)*	(−0.65)
$\hat{A}_{43}$	0.04307	0.02789	−0.02314	−0.0090
	(2.05)*	(0.06)	(−0.02)	(−0.03)
$\hat{A}_{44}$	0.03029	0.03067	0.07962	0.08962
	(1.23)	(0.22)	(2.07)*	(0.72)
$\widehat{B}_{11}$	0.96244	0.95726	0.93409	0.91564
	(4.04)**	(4.86)**	(3.74)**	(4.07)**
$\widehat{B}_{12}$	−0.21566	−0.14942	−0.16048	−0.11960
	(−1.72)	(−1.18)	(−1.46)	(−0.95)
$\widehat{B}_{13}$	−0.97081	−1.47327	−0.22508	−1.13649
	(−2.95)**	(−1.65)	(−0.13)	(−1.16)
$\widehat{B}_{14}$	−1.04841	−0.21626	0.14238	−0.40067
	(−2.15)*	(−0.61)	(0.07)	(−1.04)
$\widehat{B}_{21}$	−0.03084	−0.06682	0.00718	−0.04082
	(−0.47)	(−0.79)	(0.06)	(−0.46)
$\widehat{B}_{22}$	0.32090	0.35094	0.28719	0.33303
	(1.92)	(2.27)*	(1.67)	(2.11)*
$\widehat{B}_{23}$	−0.03238	0.37905	−0.02819	−0.08442
	(−0.02)	(0.28)	(−0.01)	(−0.05)

(*continued on next page*)

Table 3 (*continued*)

	Eurodollar futures + foreign exchange forward			
	+BP	+DM	+JY	+SF
$\widehat{B}_{24}$	0.09164	0.00262	−0.91672	−0.11106
	(0.18)	(0.00)	(−0.37)	(−0.20)
$\widehat{B}_{31}$	−0.00630	−0.00201	−0.00019	0.00074
	(−0.99)	(−0.40)	(−0.02)	(0.13)
$\widehat{B}_{32}$	−0.03680	−0.02718	−0.01120	−0.03158
	(−2.46)*	(−1.75)	(−0.91)	(−2.60)**
$\widehat{B}_{33}$	0.34962	0.39594	0.42380	0.30841
	(1.84)	(2.36)*	(2.91)**	(1.88)
$\widehat{B}_{34}$	0.84555	0.87054	0.84364	0.88450
	(4.03)**	(4.26)**	(2.50)*	(4.24)**
$\widehat{B}_{41}$	−0.01162	−0.000278	0.00148	−0.01389
	(−1.18)	(−0.03)	(0.12)	(−1.40)
$\widehat{B}_{42}$	0.00519	0.00590	0.00744	0.01137
	(0.27)	(0.32)	(0.52)	(0.81)
$\widehat{B}_{43}$	0.36644	−0.27013	−0.00360	0.30862
	(1.65)	(−1.51)	(−0.02)	(1.61)
$\widehat{B}_{44}$	0.05731	0.02814	0.01843	0.04649
	(2.08)*	(2.37)*	(1.98)*	(2.80)**
Log likelihood[b]	−2170.75	−2139.71	−2058.48	−2110.52
LR test: $A = B = 0$	328.30	355.91	169.97	149.51
$Q(24)$: spot1[c]	24.56	25.12	25.59	24.71
$Q(24)$: spot2	30.68	29.94	30.13	29.31
$Q(24)$: futures	33.61	33.62	33.60	33.70
$Q(24)$: forward	28.56	26.38	21.33	24.70
$Q^2(24)$: spot1	28.73	29.65	28.75	28.61
$Q^2(24)$: spot2	21.94	27.87	28.60	23.43
$Q^2(24)$: futures	19.65	19.59	19.61	19.71
$Q^2(24)$: forward	24.38	25.68	29.87	24.22

Notes: The estimates of $C'C$ matrix of H_t are not reported here due to a space problem. The numbers in parentheses are asymptotic t-statistics. $Q(24)$ is the Ljung-Box statistic for 24th order serial correlation in the residuals; $Q^2(24)$ is a Ljung-Box statistic for residual GARCH effects in the squared standardized residuals. Both $Q(24)$ and $Q^2(24)$ are distributed $\chi^2_{(24)}$ and have 95% critical value 36.42.

[a] The likelihood ratio test statistic for the null of $A = B = 0$ is $\chi^2_{(8)}$ that has 95% critical value 15.51.

[b] The likelihood ratio test statistic for the null of $A = B = 0$ is $\chi^2_{(32)}$.

[c] Spot1 and spot2 signify the return from loan extensions and from foreign exchange operations, respectively.

* Statistical significance at less than 5% level.

** Statistical significance at less than 1% level.

in panel B) is (are) not significantly different from zero, indicating that expected returns to holding Eurodollar futures and foreign exchange forward are zero. This implies that the expected-utility-maximizing hedging rule is consistent with the minimum variance rule under GARCH model (10). Multivariate GARCH parameter estimates $\hat{A}_{11}$ through $\widehat{B}_{22}$ for panel A ($\hat{A}_{11}$ through $\widehat{B}_{44}$ for panel B) are highly significant for a number of cases, indicating that the residual variances and covariances are changing with time and GARCH estimation procedures should give us better covariance estimates at any point in time than conventional regression methods.

Diagnostics on the residuals suggest that the model fits the data well. Tests for autocorrelations of the standardized residuals and squared standardized residuals using the Ljung-Box Q-statistics indicate that, for lags 1 through 24, no autocorrelation is present in any of the return variables (the $Q(24)$ and $Q^2(24)$ statistics are all insignificant). The highly-significant likelihood ratio statistics for any type of hedging are evidence supporting that the GARCH model describes each return series better than the conventional constant covariance model. Overall, a multivariate GARCH model with a positive definite parameterization appears to adequately describe the residual autocorrelation and conditional second-moment properties of the data.

Conditional dynamic hedge ratios are calculated by the conditional covariances between spot and futures/forward returns, and the conditional variances of futures/forward returns obtained by the path of $\widehat{\mathbf{H}}_t$ from multivariate GARCH model (10).

The results of the optimal dynamic hedge ratios are plotted in Figs. 1–5. The solid line represents separate hedge ratios and the dotted line represents simultaneous hedge ratios. The plots reveal that all of the dynamic hedge ratios, regardless of hedging strategies, are clearly time-varying and have a substantial degree of volatility. None of the dynamic hedge ratios is shown to be consistent with the conventional constant optimal hedge ratios.

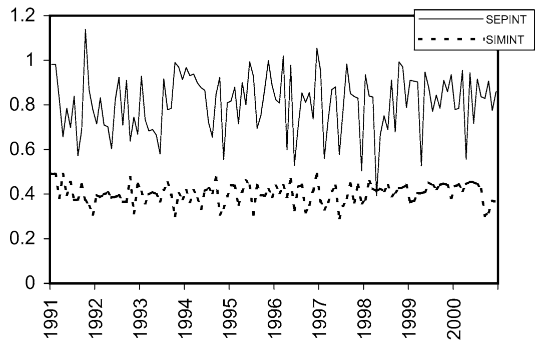

Fig. 1. Hedge ratios for interest rate risks.

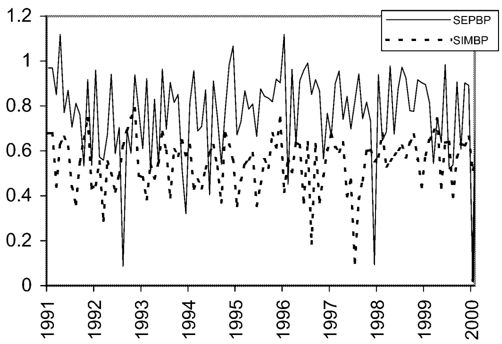

Fig. 2. Hedge ratios for BP exchange risks.

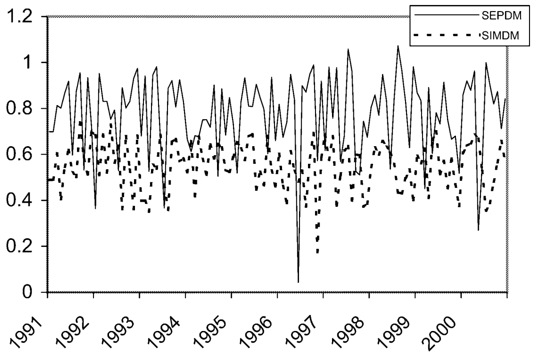

Fig. 3. Hedge ratios for DM exchange risks.

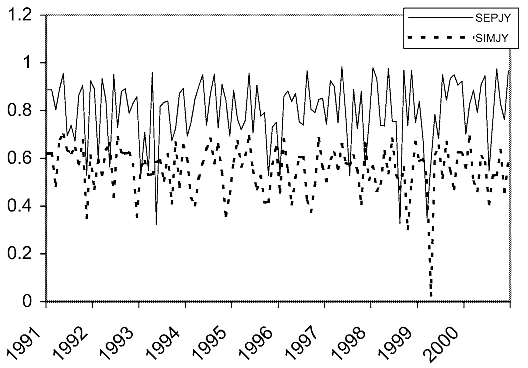

Fig. 4. Hedge ratios for JY exchange risks.

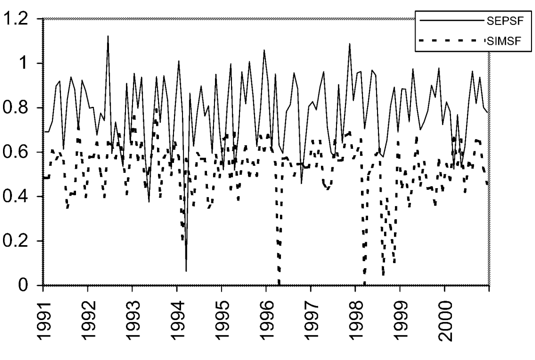

Fig. 5. Hedge ratios for SF exchange risks.

Note that simultaneous hedge ratios are lower than separate hedge ratios for all types of hedging. This indicates that the separate hedge ratios overstate the optimum magnitude for risk minimization for banks that engage in both domestic loan extensions and foreign exchange operations, implying that the separate hedging strategy "overhedges" (i.e., uses too many futures contracts) as compared to the simultaneous hedging strategy. This overhedging arises because implementing a balance sheet adjustment of loan extensions and foreign exchange operations as part of normal bank operations can help the bank maintain a certain degree of natural hedge against exposure to the extent that returns from the loan extension and foreign exchange operations are less than perfectly correlated in a standard portfolio problem. The presence of the natural hedge for banks that engage in both domestic banking activities and foreign exchange operations diminishes the need for external hedging using futures/forward contracts. This implies that the hedging need for the bank under the simultaneous hedging strategy is lower than that under the separate hedging strategy, thus bringing about an overuse of futures/forward contracts under the separate hedging strategy.

3.3. Comparisons of hedging performance

In this section, we make performance comparisons between simultaneous and separate hedging strategies within a mean/variance framework. To this end, we measure expected returns and variances by taking expected values and variances for Eq. (9). The hedge ratio vector needed for Eq. (9) is obtained from the multivariate GARCH model (10).

Table 4 presents both in- and out-of-sample results for expected returns and standard deviations of Eq. (9) and the percentage improvements of the simultaneous hedge as compared to the separate hedge. Panel A of Table 4 reveals that, within sample, a simultaneous hedging strategy noticeably outperforms a separate hedging strategy in every case in terms of both raising the expected return on the portfolio and reducing the conditional standard deviation of portfolio returns. This phenomenon is salient for the DM forward hedging in which a simultaneous hedging strategy raises the expected return on the portfolio by 15.9% and reduces the standard deviation of the portfolio returns by 20.5%. For other currencies alike, simultaneous hedging uniformly outperforms separate hedging. This suggests that banks will substantially enhance their hedging performance by adopting a simultaneous hedging method.

Table 4
Performance evaluation

Hedging method	Loan extensions + (%)							
	BP		DM		JY		SF	
	$E(R_p)$	$\sigma(R_p)$	$E(R_p)$	$\sigma(R_p)$	$E(R_p)$	$\sigma(R_p)$	$E(R_p)$	$\sigma(R_p)$
A. In-sample performance evaluation								
Separate	2.3825	4.0292	2.2615	3.9816	2.3710	3.9700	2.3379	4.0904
Simultaneous	2.6532	3.2700	2.6222	3.1672	2.4244	3.5347	2.5822	3.1466
	(+11.4)	(−18.8)	(+15.9)	(−20.5)	(+2.3)	(−11.0)	(+10.5)	(−23.1)
B. Out-of-sample performance evaluation								
Separate	2.1214	4.3689	2.1633	4.2536	2.3052	4.2400	2.1496	4.2330
Simultaneous	2.3787	3.6630	2.3678	3.5128	2.4713	3.6194	2.3802	3.7541
	(+12.1)	(−16.2)	(+9.5)	(−17.4)	(+7.2)	(−14.6)	(+10.7)	(−11.3)

Notes: The figures in parentheses are the percentage improvement of the simultaneous hedge over the separate hedging strategy. The expected return and variances are obtained from Eq. (9), assuming that banks forecast the next month's hedge ratios using the information available at this month.

In an attempt to better evaluate the performance of the hedging strategies, we also conduct performance evaluation using out-of-sample data. The out-of-sample results are obtained following Kroner and Sultan (1993). We initially estimate two different hedging methods using data up to the first 60 observations (from January 1991 to December 1995) and withholding the rest of the sample (from January 1996 to December 2000). Hedge ratios are forecasted for the following month (January 1996) by computing one-month forecasts of the covariance and variance. Hedge ratios are successively forecasted every month by adding a new observation, i.e., in the following month (January 1996), a hedge ratio is forecasted for February 1996 using the data available in January 1996. This process is continued on a monthly basis until the end of data set, thus giving 61 forecasted hedge ratios. These hedge ratios are substituted into Eq. (9) to yield the portfolio expected return and standard deviation.

Panel B of Table 4 containing out-of-sample results reveals that simultaneous hedging strategy outperforms separate hedging strategy for all currencies, as with the in-sample results. Using simultaneous hedging produces a higher expected return and, at the same time, a lower risk than that for separate hedging does.

In sum, both within-sample and out-of-sample, simultaneous hedging outperforms separate hedging within the risk-return profile of the bank portfolio. The improvement of risk reduction in simultaneous hedging over separate hedging can be explained within the context of conventional portfolio theory: the addition of any asset to the original portfolio reduces total risk to the extent that returns of the assets in the portfolio are less than perfectly correlated. A simultaneous hedging strategy effectively takes into account correlations between loan extensions and foreign exchange operations within a portfolio context, while separate hedging does not. This indicates that both interest rate and exchange risks can be reduced more with simultaneous hedging than with separate hedging. A simultaneous hedging strategy can effectively outperform separate hedging in reducing the risk exposure. The enhancement in expected return in favor of simultaneous hedging can be attributable to cost efficiency. While separate hedging entails overhedging effects as described in previous section and thus brings about ineffective or overly expensive risk management, simultaneous hedging facilitates more cost-effective and hence less expensive risk management on an overall basis (see, for example, Meulbroek, 2002).[13]

The above results indicate that simultaneous hedging strategies stochastically dominate separate hedging strategies in terms of risk-return efficiency. This risk-return efficiency improvement of simultaneous hedging over separate hedging is statistically tested in the following section.

3.4. Statistical significance of performance improvement

To identify any statistical significance of performance enhancement from a simultaneous hedging strategy, we employ mean–variance efficiency tests developed by MacKinlay and Richardson (1991) in a generalized method of moments (GMM) framework. The

[13] We are indebted to an anonymous referee who also suggested that if transaction costs were incorporated, separate hedging will result in hedgers incurring larger transactions costs and thus the returns would be lower, when viewed on a contract by contract basis.

GMM-based efficiency tests have often been applied to test whether or not adding one asset to the original portfolio significantly improves the risk-return profile of the original portfolio (see, for example, Glen and Jorion, 1993, and Mun and Morgan, 1997).

Defining M as the number of original assets and N as the number of additional assets, we consider the following multivariate GMM regression:

$$Y_{i,t} = \alpha_i + \sum_{j=1}^{M} \beta_{ij} X_{j,t} + e_{i,t} \quad \forall i = 1, \ldots, N, \tag{11}$$

where $Y_{i,t}$ are the additional N asset returns at time t, i.e., the returns from foreign exchange operations including foreign exchange forward transaction; $X_{j,t}$ are the (original) portfolio returns of M assets at time t, i.e., the returns from loan extensions and interest rate futures transaction, and $e_{i,t}$ is the error term for asset i at time t.

Tests of performance improvement are conducted by estimating the unrestricted system and then testing the following null hypothesis:

$$H_0: \quad \alpha_i = 0, \quad \forall i = 1, \ldots, N.$$

The null hypothesis implies that the addition of foreign exchange risk hedging with forward contracts to the original hedging set of loan extensions and interest rate futures transaction does not improve the hedging performance as measured by mean–variance efficiency. That is, the hypothesis reflects that the hedging performance does not improve with simultaneous hedging as compared to separate hedging. Statistical significance of the null hypothesis is tested using the Wald (W) statistic that is asymptotically distributed as chi-square with N degrees of freedom as the following:

$$W = (T - N - 1)\hat{\alpha}' \left[D' S^{-1} D\right]^{-1} \hat{\alpha} \sim \chi^2_N, \tag{12}$$

where T is the number of observations and $[D' S^{-1} D]^{-1}$ is the variance-covariance matrix of Newey and West (1987), which is heteroskedasticity- and autocorrelation-consistent.

The values of the chi-square statistics for the null hypothesis are presented in Table 5. The null hypothesis is a chi-square statistic with two degrees of freedom. The values of the chi-square statistic range from 10.1 to 19.6 within sample and from 18.2 to 23.8 out of sample, all of which correspond to levels of significance well below 1%. These large values of chi-square statistic provide strong evidence against the null hypothesis that simultaneous

Table 5
Performance improvements of simultaneous hedging method (as measured by mean–variance efficiency)

	Hedging interest rate risk + foreign exchange risk			
	BP	DM	JY	SF
	$\chi^2(2)$	$\chi^2(2)$	$\chi^2(2)$	$\chi^2(2)$
In-sample	16.4352**	19.6446**	10.0824**	18.7462**
Out-of-sample	21.6150**	23.8235**	18.2256**	20.4843**

Notes. The Wald statistic is asymptotically distributed as chi-square with two degrees of freedom as the following: $W = (T - 3)\hat{\alpha}'[D' S^{-1} D]^{-1}\hat{\alpha} \sim \chi^2(2)$. Note that the chi-square statistic for the null is $\chi^2(2)$ that has 9.210 for 99% critical value.

** Significantly different from the null hypothesis at the 1% level.

hedging does not improve hedging performance over separate hedging. The hypothesis test conducted here lends statistical significance to the performance analysis in the previous section.

4. Conclusion

This paper investigates hedge ratio dynamics for the US banking system composed of banks with exposure to domestic interest rate and foreign exchange risks. Within a mean–variance framework, the paper evaluates hedging performance when interest rate and foreign exchange risks are hedged *separately* versus *simultaneously*. In particular, this paper seeks to understand whether or not a simultaneous hedging strategy can statistically improve performance relative to a separate hedging strategy.

Optimal hedge ratios for separate and simultaneous hedging strategies are estimated using a multivariate GARCH model. Hedge ratio plots presented in this paper indicate that the separate hedge ratio consistently overstates the magnitude of futures/forward contracts needed relative to that of the simultaneous hedge ratio. This implies that separate hedging overhedges the bank's balance sheet exposure and thus leaves risks in the portfolio that could otherwise be transferred to other parties. This is attributable to the presence of a natural hedge in normal bank operations so that part of interest rate and foreign exchange risks is reduced even before using futures or forward contracts whenever returns from loan extensions are less than perfectly positively correlated with returns from foreign exchange operations.

Both in-sample and out-of-sample evidence presented in this study indicate that simultaneous hedging outperforms separate hedging. Banks will achieve better hedging performance when hedging interest rate and foreign exchange risks simultaneously rather than separately. The improvement of risk reduction in simultaneous hedging over separate hedging can be explained by conventional portfolio theory that adding any asset to the original portfolio reduces total risk to the extent that returns of the assets in the portfolio are less than perfectly correlated. The enhancement in expected return in favor of simultaneous hedging can be attributable to cost efficiency. The mean-variance efficiency test performed in this study statistically reinforces the significance of hedging performance improvement of a strategy to simultaneously hedge over separately hedge.

Acknowledgments

The comments of an anonymous referee and William Christie (the editor), and the suggestions of Anjan Thakor (the managing editor), have been very helpful in improving this paper. The authors thank the participants of the 2001 FMA meeting for their comments. The first author gratefully acknowledges financial support from the Division of Business and Accountancy, Truman State University.

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