

**Bank Hedging in Futures Markets: An Integrated Approach to Exchange and Interest Rate Risk**

**Management**

by

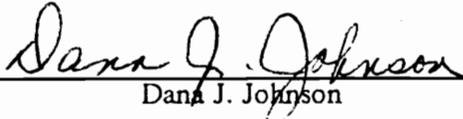
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in  
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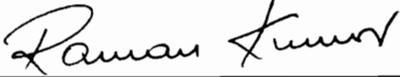
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(ABSTRACT)

This study investigates the simultaneous use of interest rate and currency futures markets to hedge the exchange and interest rate risks faced by banks. Banks in this study accept short-term variable rate deposits, hold many different foreign currencies, and make long-term fixed rate loans. The expected utility maximization model shows that in a two-period framework the bank's optimal simultaneous hedge ratios for risks associated with exchange rate, interest rate, and anticipatory positions are given by the coefficients of the theoretical *multivariate* multiple regression of returns from trading the (spot) instruments being hedged on those from trading the futures contracts. Unlike previous studies, capital adequacy is shown in this study to be an important factor determining the bank's optimal futures position. The bank's decisions on loan extensions and interest rate futures positions are shown to be affected by the existence of foreign exchange operations and the availability of foreign currency futures contracts. It is also shown that the (optimal) hedging decisions anticipated for later time periods influence current decisions, which implies that hedge positions are intertemporally dependent.

Based on the theoretical analyses, five testable hypotheses are derived: (i) Capital adequacy irrelevance hypothesis, (ii) Naive-single market hypothesis, (iii) Own market hypothesis, (iv) Intertemporal position irrelevance hypothesis, and (v) International

banking hypothesis. These hypotheses are tested using the generalized method of moments procedure. The empirical results show that (a) capital adequacy is highly relevant for the bank's decision on optimal futures positions, (b) it is not optimal for the bank to take a *naive* position in the corresponding futures contracts to hedge a specific type of spot position, (c) cross-hedging is necessary to increase hedging performance, (d) the bank's anticipated positions in foreign currency spot and futures contracts next period affect the current decisions on optimal spot and futures positions, and (e) international banking activity, as it is interrelated with domestic and international credit markets, must be considered when the bank makes decisions on optimal futures positions. Finally, the optimal hedge ratio estimates demonstrate strong evidence that banks should use the futures markets to a substantially greater extent for hedging overall market risk compared to when they hedge each component of market risk separately.

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# Chapter 1

## INTRODUCTION

### 1.1 Background

The greater integration of economies throughout the world in the past two decades has made it imperative that U.S. companies maintain a global perspective on their competition and their markets. The creation of a single integrated market by the European Community (EC) in 1992 highlights the need for flexibility and international financial planning by U.S. companies. As bank customers have increased their interest in and consideration of foreign markets, banks have found it necessary to maintain an active presence in the foreign exchange market in order to offer a more competitive service to a growing customer base and to take advantage of the profit opportunities perceived in fluctuating exchange rates and interest rates. However, with the expansion of international financial relationships and the continued liberalization of cross-border cash flows, financial institutions become more and more exposed to the risks associated with international transactions.

Financial exposure (or market risk) of banks operating in the foreign exchange market can be separated into two broad categories: interest rate exposure and foreign exchange rate exposure. Interest rate exposure arises when financial assets and liabilities have a mismatch in maturity or when interest rates of assets and liabilities of the same maturity are not perfectly correlated, or when floating rate financial commitments create uncertainty with regard to future cash flows and there is an unexpected change in the level of interest rates. Exchange rate exposure occurs whenever the bank has a positive (or negative) net asset position in a particular foreign currency subject to an unexpected fluctuation in exchange rates [See, Brodt (1984)]. If foreign currency assets are greater (smaller) than liabilities, an appreciation (depreciation) in the foreign currency generates profits (losses). In times of volatility in interest rates and foreign exchange rates, an excessive financial exposure can have a very significant impact on an institution's financial performance, and consequently financial exposure requires management's constant attention.

## **1.2 Motivation of the Study**

The development of forward and futures markets has provided financial intermediaries, among others, with a vehicle for hedging against unanticipated changes in exchange and interest rates. In fact, a number of large U.S. banks have been actively engaging in transactions of both interest rate futures and foreign exchange forwards/currency futures. Banks need flexible ways to hedge funding costs and foreign exchange exposure and have responded to the growing sophistication of the financial markets [See annual reports of large banks]. Numerous studies have, in great detail, examined the issue of hedging interest rate risk using financial futures contracts and hedging foreign exchange

risk using currency futures contracts in a separate framework. As Smirlock and Kaufold (1986) stated, "most papers that prescribe methods for hedging foreign exposure address exchange risk only, while a separate literature is devoted to the measurement and management of the interest rate risk of securities denominated in domestic currency". Consequently, the theoretical results based on an isolated analysis of only a particular risk of banking activity may not simultaneously hold true. This is because each model is developed under a different, and often mutually exclusive, set of assumptions.

The need for simultaneous management of exchange and interest rate risks faced by the bank which engages in both domestic and foreign operations is obviated by the well-known interest rate parity (IRP) theorem.<sup>1</sup> The IRP theorem implies that a change in U.S. interest rates produces changes in Eurodollar rates, exchange rates, and foreign interest rates. The reverse may happen — that is, the change in Eurocurrency and foreign exchange rates produced by a domestic interest rate change may, in turn, produce a feedback effect on domestic interest rates. The interest rate of a given currency will be influenced by the interest rate development of other currencies and the financial markets' expectations on the future foreign exchange rates of the currencies. The interdependence of these macro-variables will make it important for banks to coordinate their policies toward global risk management.

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<sup>1</sup> This study is not at the center of discussion about the validity of the IRP theorem. Rather, we recognize from international monetary economics that there exists an interdependence between movements of exchange rates and interest rates.

### 1.3 Literature Review

Virtually no attempt has been made in the literature to deal simultaneously with both the exchange and interest rate risk until Smirlock and Kaufold (1986) pioneered the modelling of this issue, while Grammatikos, Saunders, and Swary (1986), Kawai and Zilcha (1986), and Kaufold and Santomero (1986) have focused on a similar issue in a somewhat different (but quite related) context. Grammatikos, Saunders, and Swary (1986) investigate the risks of U.S. banks' foreign currency positions when both exchange rate and foreign interest rate uncertainty are present. Kawai and Zilcha (1986) consider a risk averse firm which engages in international trade of commodities and faces exchange rate and commodity price uncertainty. Kaufold and Santomero (1986) consider the management of credit and exchange rate risks faced by the international banking firm. Among these studies, two different theoretical hedging approaches can be observed. One is the duration-based portfolio hedging approach as seen in Smirlock and Kaufold (1986) and Grammatikos, Saunders, and Swary (1986). This approach, assuming flat term structures, models bank managers as focusing on the change in the value of the firm's stream of future foreign currency cash flows. The duration of the cash flow stream is used as the measure relating interest and exchange rate changes to value changes. The firm's optimal hedging strategies are derived by minimizing the variance of the foreign currency portfolio in the same manner as Ederington (1979). The advantage of this approach is the explicit consideration of exchange and interest rate exposure faced by the bank. On the other hand, however, this approach has several important shortcomings. First, since the model is formulated as one of minimizing risk, the trade-off between risk and return is not addressed. Second, the variance of the foreign currency portfolio may not be of particular concern to bank managers. Managers

should be concerned with the variance of a broader portfolio, namely, the asset-liability portfolio, rather than simply the foreign currency component of the portfolio. Most importantly, assuming a flat term structure is a shortcoming. Although a flat term structure makes many mathematical and empirical issues more tractable, several important inconsistencies arise from this assumption. For example, a maturity mismatch between the hedged instrument and the futures contracts would have no adverse effect under a flat term structure, because rates for all maturities would be identical. Similarly, the relationship of the delivery date to the date of hedged transaction would be irrelevant; spot rates for all maturities would be identical and futures rates for all delivery dates would be identical, too. Thus, in a world with a flat term structure, maturity and delivery date mismatching are irrelevant. Finally, this duration-based portfolio hedging approach is equivalent to minimizing portfolio variance when spot and futures value changes are perfectly correlated, which is typically rejected by empirical evidence [See, Hilliard and Jordan (1989)]. (Note that this is, however, based on the premise that value changes in the spot and futures market are proportional to the duration of the security).

An alternative approach is based on the neoclassical theory of the firm under uncertainty [Kawai and Zilcha (1986) and Kaufold and Santomero (1986)]. Two parts of the literature are slightly different in their treatment of the objective: expected utility maximization versus utility maximization. Kawai and Zilcha (1986) consider a competitive, risk averse international manufacturing firm with von Neumann-Morgenstern utility function and derive the firm's optimal hedging strategies by maximizing the expected utility of its foreign revenues less domestic-currency expenses. Their model is quite general in that it places no restrictions on the utility function other than concavity as well as on the probability distribution of profits. However, its ability to apply to the analysis of bank risk management is questioned. The firm's decisions on the objectives

and operational methods of risk management should depend on its budget constraint. Kawai and Zilcha (1986) do not consider a budget constraint because they consider the simple case of a firm with 100% of assets in the spot commodity and no debt financing and thus they can completely ignore balance sheet risks. In addition, in Kawai and Zilcha (1986) the product of the exchange rate and the commodity price denominated in foreign currency plays the central role, and the relationship between exchange rate changes and commodity price changes in international trade is not addressed. Even without resorting to the purchasing power parity theorem, it is obvious that nominal variations in the commodity price are closely linked to fluctuations in the exchange rate. Ignoring the interdependence between exchange rate changes and commodity price changes gives an incomplete view of the character of the risks associated with international trade in a broader context. Reducing exchange rate risk by means of a forward contract may expose the firm to commodity price risk on the forward contract and vice versa.

Kaufold and Santomero (1986) consider an international banking firm that engages in domestic and foreign lending and borrowing and derive the bank's optimal allocation of assets and liabilities by maximizing the concave utility function of the bank. They deal solely with internal hedging as discussed below. Technically, hedging may be implemented either internally or externally. Managing exposure internally entails using sources within the organization to hedge exposure. For banks, balance sheet manipulation falls into this area. External methods are those that require the hedger to venture outside the organization to contract for aid in protecting exposure. These include bank forward foreign exchange contracts, currency futures and options. Internal hedging through balance sheet adjustments does not consider the use of forward-futures contracts for hedging the risks. Implementing asset and liability adjustments as a part of

normal operations can help the bank maintain a natural hedge against exposure; however, the ability to apply this technique varies from hedger to hedger. The smaller bank that operates in foreign exchange markets almost entirely on a transaction-by-transaction basis may have limited tools for internal hedging. Conversely, larger banks have a broad spectrum of available techniques from which to choose. Banks can be better off if they reduce their risk by futures hedging (external hedging). Smith and Stulz (1985) provide two explanations of this as follows: first, if hedging reduces the variability of pre-tax firm profit, then the expected tax liability is reduced and the expected post-tax value of the bank is increased, so long as the cost of futures hedging is not too large. Second, bank managers are frequently unable to diversify risks specific to their claims on the banks. Therefore, risk averse managers require extra compensation to bear the nondiversifiable risk of the claims. As long as the reduction in compensation of managers together with the increased revenues from the tax structure exceeds the costs of futures hedging, external hedging increases the value of the bank.

While optimal forward-futures positions associated with hedging two risks simultaneously can be found in Kawai and Zilcha (1986) (for exchange rate and commodity price risks) — and Smirlock and Kaufold (1986) (for exchange and interest rate risks), we note that neither of those studies has approached the issues within the context of a banking firm, nor do they reach a satisfactory conclusion. Kawai and Zilcha (1986) find that if the forward exchange market is unbiased and the forward-futures markets are jointly unbiased, then the optimal forward-futures contracting is what they call a “full-double hedge”; each of the two optimal hedge ratios for output and commodity futures is exactly one (unity). This finding is exactly the same as what traditional hedging theory views — that is, the hedger takes a position in the futures market that is opposite in sign but at the same number of units as his spot position. If futures prices reflect expected

spot prices, then there is no reason why futures price changes should equal changes in spot prices — that is, there need not be a one-to-one correspondence between spot and futures price changes, particularly when expected prices do not change. Smirlock and Kaufold (1986) find that the optimal hedge ratio is determined by the covariances among and variances of changes in domestic and foreign interest rates, exchange rates, appropriate discount rates, and the duration of the security being hedged. The hedge ratio is expressed in terms of the duration and the simple regression coefficients to quantify some of the relationships needed to implement the optimal hedging strategy. Because this minimum-variance hedge ratio does not take the return on the hedge portfolio into account, regression-based hedge ratios will not necessarily be optimal for all types of expected utility functions. Both Kawai and Zilcha (1986) and Smirlock and Kaufold (1986) provide only a single optimal hedging decision with regard to exchange rate risk. Since returns from trading foreign currencies are likely correlated with returns from trading currency futures, as are currency futures returns likely correlated among themselves, the optimal hedge for each currency in an n-currency asset portfolio may differ from the optimal hedge for each currency held on its own.

#### **1.4 Overview of the Study**

All of the models discussed above take an essentially one-period perspective. Duration-based models assume a one time shift though the cash flows are over many calendar periods. The models based on the neoclassical theory of the firm only provide for a single realization of random variables and a single hedging decision. However, hedge positions are revised as new information is received by a bank and cash flow in one period affects the bank's ability to take advantage of opportunities in the next pe-

riod. Therefore, the revelation of new information and the possession of reinvestment opportunities create another decision point, and thus the situation is intrinsically a two-period decision problem. The theoretical model employed in this study is a two-period model for which the bank facing both exchange and interest rate uncertainty maximizes an expected utility function defined over terminal wealth to choose optimal levels of decision variables. In these respects, the problem is similar to those addressed by Baesel and Grant (1982) and Morgan and Smith (1987). What distinguishes the model here is that reinvestment opportunities in the second period for cash flows generated in the first period are explicitly considered. At the start of period two, the bank will have at its disposal the first period profits that will be reinvested at the random rate prevailing in the second period. Terminal profits are, therefore, equal to the first period random profits plus any random return on reinvestment of the first period profits plus the second period random profits. This distinction allows a richer analysis of the issue of exchange and interest rate exposure in the banking firm and implies an evolution of the hedging position over time. This is because the second period random rate will play a significant role in theoretical and empirical analyses. For example, even though futures markets are martingale-efficient in removing excess profits, there can still exist profit opportunities in the futures market positions unless the second period random rate (reinvestment rate) is foreseeable or joint probability distribution of the random rate and futures rates is independent. This is sharply contrasted with extant bank hedging literatures [e.g., Koppenhaver (1985), Morgan, Shome, and Smith (1988)].

The following two characteristics surrounding the use of futures contracts as hedging instruments are explicitly considered in our model. First, it is not uncommon that banks hold currency asset positions in many different currencies concurrently and hold currencies for which forward and futures markets do not yet exist and are illiquid. In this

situation, cross hedging is necessary [See, Anderson and Danthine (1981) ].<sup>2</sup> We incorporate this situation into the model via multiple spot and currency futures contracting. Second, the bank can use futures to hedge a particular operation or to hedge the overall market risk faced by the bank — these are termed microhedging and macrohedging, respectively. As concluded by Kolb, Timme, and Gay (1984), it will, in general, be in the best interest of the financial intermediary's stockholders and managers to hedge its risk on a macro basis. A discretionary microhedging policy may increase the intermediary's overall risk by offsetting any natural internal hedges. A financial intermediary is naturally and perfectly hedged, for example, if it reprices assets and liabilities simultaneously and by the same amount. In practice, banks such as Citicorp and Chase Manhattan Bank manage their exchange and interest rate risks as part of their overall interest rate and foreign exchange trading activities which include both funded asset and liability positions (on-balance sheet positions) and non-funded positions (off-balance sheet positions).

This study, within a two-period framework and in the presence of multiple contracts on different instruments, sheds light on the optimal macrohedging behavior of a risk averse bank that hedges simultaneously its exchange and interest rate risks. Whereas the methodology used and the results provided are quite general, this study deliberately focuses the simultaneous analysis on hedging both exchange and interest rate risks. In particular, a unified framework is developed by integrating two strands of the literatures on hedging: studies on bank hedging behavior under interest rate uncertainty with interest rate futures markets [Koppenhaver (1985), Morgan and Smith (1987), Morgan,

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<sup>2</sup> In contrast to Anderson and Danthine (1981), Levi (1979) has documented that in a world where cross-elasticities between foreign currency movements are known, one forward contract will be complete enough to hedge against variations in any of currency values. As a practical matter, however, the possibilities of hedging in this way would be limited since in an uncertain world the cross elasticities will be stochastic.

Shome, and Smith (1988), etc.] and studies on hedging behavior under exchange rate uncertainty with currency futures markets [Hill and Schneeweis (1981, 1982), Grammatikos and Saunders (1983), Park, Lee, and Lee (1987), Benet (1990)]. We also provide a comparative static analysis in which we investigate the effects of introducing bank foreign exchange operations on the optimal levels of loan extensions and interest rate futures positions. The objective is to investigate the impact of such operations upon the decisions of a risk averse bank with regard to the loan extensions and the interest rate futures positions. In addition, we prove, in a much different context, Roll and Solnik's finding that the IRP theorem still holds under uncertainty in its usual form. Roll and Solnik (1977) considered the impact of uncertainty on the IRP condition assuming perfect capital markets and capital mobility. Their methodology is based on a continuous time international capital asset pricing model (ICAPM) developed by Solnik (1973). Therefore, they implicitly assume two-parameter utility functions in their derivation. Our derivation is based on the assumption that a risk averse bank with von-Neumann Morgenstern utility function takes positions in foreign currencies and its return is the interest rate for the currency and period considered plus any exchange rate variation. The generality in our derivation is greater than in Roll and Solnik's in the sense that we use a general utility function on which no restrictions are placed.

Finally, we implement empirical tests based on the theoretical analyses. In particular, we seek to estimate joint optimal hedge ratios and implement hypothesis tests. Five testable hypotheses are derived from the theory developed in this study: (i) *Capital Adequacy Irrelevance Hypothesis*, (ii) *Naive – Single Market Hypothesis*, (iii) *Own Market Hypothesis*, (iv) *Intertemporal Position Irrelevance Hypothesis*, and (v) *International Banking Hypothesis*. We use GMM (Generalized Method of Moments) model suggested by Hansen (1982) and extended by Newey and West (1987) as an

econometric technique. The integrated framework of interest and currency futures markets in our model requires a sophisticated econometric technique that allows for not only simultaneous estimation of different futures hedge ratios (and thus a system-wide application) but also time-varying variance represented as conditional heteroskedasticity — returns of international financial assets are statistically characterized as having conditional heteroskedasticity by, for example, Cumby and Obstfeld (1983), Hansen and Hodrick (1980, 1983), Hsieh (1988), Lewis (1990). The GMM model provides a way to estimate the parameters of system and achieve *consistency* of estimators in the presence of conditional heteroskedasticity.

## 1.5 Theoretical Findings

Major theoretical findings in this study can be summarized as follows:

- (1) The bank's optimal simultaneous hedge ratio such that risks associated with exchange rate, interest rate, and "anticipatory position risk" are minimized simultaneously is given by the coefficients of the theoretical *multivariate* regressions of returns from trading the instruments being hedged on those from trading the futures contracts.
- (2) The bank's optimal hedge position is affected by capital adequacy via variance-covariance matrix of futures returns and covariances among deposit cost savings per unit capital and futures returns.
- (3) The optimal hedging decisions anticipated for future time periods influence current decisions, which implies that hedge positions are intertemporally dependent.

(4) Hedging only with interest rate futures contracts without the recognition of the interdependence between interest and exchange rates could be misleading.

(5) The existence and availability of foreign exchange operations affects significantly the bank's decisions on loan extensions and interest rate futures positions.

(6) Within a multi-period framework, the bank's speculative demand for futures contracts consists of two components: a conventional speculative demand and an intertemporal autocorrelation of futures return which reflects the linkage between current and future time periods' speculative opportunities.

(7) Regulatory control of futures use by banks is possible only if *continued monitoring* of the bank's futures policy is made. Because hedging demand has an important intertemporal component, one time fine-tuning policy is not effective.

## **1.6 Empirical Findings**

Our empirical results demonstrate strong support for the theory developed in this study and can be summarized as follows:

(1) Capital adequacy is an important factor affecting the bank's optimal hedging decisions; the risk arising from capital adequacy can be minimized by taking an appropriate hedge only for the interest rate futures contracts.

(2) The interdependence between domestic interest rates and foreign exchange rates (and thus with foreign currency futures rates) plays a vital role in the bank's hedging decisions in the presence of both interest rate and foreign exchange rate risks.

(3) The use of the futures markets by banks is needed to a greater extent when they hedge overall market risk simultaneously rather than when they hedge each component of market risk separately.

(4) Japanese yen futures contracts provide a great deal of ability and effectiveness for hedging overall foreign exchange rate risks, whereas British pound futures contracts do not have the hedging ability of overall foreign exchange rate risks other than own exchange rate risks.

(5) Cross-hedging is necessary to hedge anticipatory foreign exchange rate risks and to increase hedging performance.

(6) The bank's current hedging decisions are greatly influenced by its anticipated positions in foreign currency spot and futures contracts to be taken at a later time period and by its engagement in international banking activity as it is interrelated with domestic banking activity.

## Chapter 2

# MODEL FRAMEWORK

This study is designed to examine the simultaneous use of interest rate and currency futures markets to hedge the exchange and interest rate risks of a risk averse bank that accepts short-term variable rate deposits, holds many different foreign currencies, and makes long-term fixed rate loans. It also explains how the bank's hedge position evolves through time with the revelation of new information.

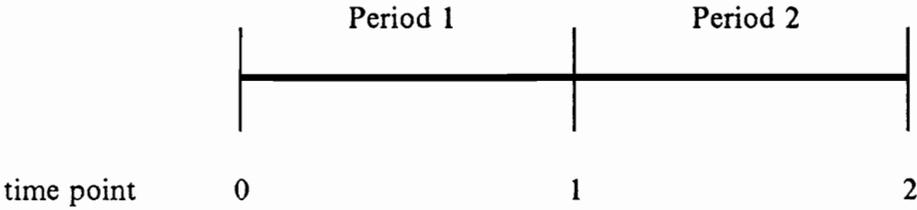
To these ends, we use a two-period model with no transactions costs and perfect capital mobility. At the start of the current period, bank managers make decisions with regard to loan extensions facing a domestic maturity mismatch problem, interest rate futures opportunities, net positions in foreign currencies, and currency futures opportunities for the current period. Also, decisions with regard to net positions in foreign currencies and currency futures positions will be, once again, made at the start of the next period when uncertainty about foreign exchange rates and futures rates at the end of the current period is resolved. (Net positions in foreign currencies equal foreign cur-

rency asset positions minus foreign currency liability positions). We assume that the bank can borrow short-term (one-period) funds in the perfectly competitive short-term deposit markets [e.g., Eurodollar and negotiable certificate of deposits (CD) markets] at a known rate in the current period but at an unknown random rate in the next period. The bank makes long-term (two-period) fixed rate loans at the start of the current period. Loans have interest payments both at the end of the first period and at the end of the second period (credit risk is ignored). Short-term deposit borrowing at a random rate and the extension of long-term loans at a fixed rate creates a mismatch in maturity. This situation creates interest rate risk. Such interest rate risk arises either when bank assets and liabilities have a maturity mismatch problem or when variable rate deposits create uncertainty with regard to future cash flows.

We, further, assume that the bank takes net (asset or liability) positions in foreign currencies at the start of the current period when exchange rates are known, subject to liquidation of net positions in foreign currencies at the start of the next period when exchange rates are unknown. This situation creates exchange rate risk. Exchange rates are assumed to be random throughout the periods (with the exception of current starting date). The bank takes another net position in foreign currencies at the start of the next period and then closes out its net currency positions at the end of the next period. This situation creates another exchange rate risk so that the bank's intertemporal hedging behavior in foreign currencies must be examined. In our model, therefore, exchange rate risk arises throughout the time horizon (except for the current starting date) whenever the bank has net positions in foreign currencies subject to unexpected changes in exchange rates.

The profits generated in the first period are assumed to be carried over to capital in the form of retained earnings at the start of the second period without being paid out as dividends. The losses generated in the first period are refinanced at the random deposit rate prevailing in the second period to make the new balance sheet balanced. Our model, therefore, explicitly considers reinvestment opportunities in the second period for cash flows generated in the first period.

To obtain a better understanding of the model, we illustrate the timing of events in the following figure.



The bank facing the exchange and interest rate risks establishes both interest rate and currency futures contracts at time 0 (at a currently known price) for deliveries of short-term funds and foreign currencies at time 1. Currency futures contracts are, once again, established at time 1 for delivery of foreign currencies at time 2 because exchange rates at time 2 are unknown and thus the conversion value of the net flows into U.S. dollar is unknown. On the contrary, interest rate futures contracts don't have to be established at time 1 because, within a two-period framework, terminal profits at time 2 are unaffected by the deposit rate at time 2. (This random rate would only be incorporated into profits if a third period was modelled.)

We assume the existence and availability of a certain type of interest rate futures contract (e.g., T-bill, T-note, Eurodollar futures contract, etc.) and  $n$ -different currency futures contracts differentiated by foreign currency (e.g., British pound, German mark, Japanese yen, etc.), all being traded at the planned dates of the bank. This provides the bank with both direct and cross hedging strategies. In the latter case, for example, exchange rate risk in a particular foreign currency can be cross hedged by participating in currency futures markets or even in interest rate futures markets.<sup>3</sup> In general, a cross hedge occurs when the instrument being hedged and the instrument deliverable against the futures contracts are highly correlated but differ with respect to risk level, coupon, or maturity, etc. This implies that the vast majority of all hedges in the interest rate and currency futures markets are cross hedges [See, Kolb (1988)].

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

$L$  = the fixed dollar amount of long-term (two-period) loans demanded at time 0.

$C_{ij}$  = the net asset position (expressed in units of foreign currency) at time  $i$  for foreign currency  $j$ , for  $i = (0,1)$  and  $j = (1,\dots,n)$ . This is a decision variable.

$\tilde{S}_{ij}$  = the (spot) exchange rate at time  $i$  (expressed in units of U.S. dollar per one unit of foreign currency  $j$ ), for  $i = (0,1,2)$  and  $j = (1,\dots,n)$ . This random variable is non-stochastic at time 0 but stochastic at other times.

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<sup>3</sup> U.S. banks appear to mainly use T-bill and Eurodollar futures contracts to cross hedge CD interest rate risk [See, Senchack and Perfect (1990)]. In addition, the use of currency futures contracts by U.S. banks is concentrated among a few currencies, notably the German mark, British pound, Japanese yen, Swiss franc, and Canadian dollar, which are the most actively traded.

$D_0, D_1$  = the level of domestic-currency denominated deposits (domestic CDs or Eurodollar CDs) received by the bank at time 0 and at time 1, respectively.

$K_0, \tilde{K}_1$  = the amount of capital used by the bank at time 0 and at time 1, respectively. The latter variable is stochastic since the random profits generated in the first period are carried over to capital in the form of retained earnings at the start of the second period.

$R_L$  = the long-term (two-period) fixed loan rate.

$\tilde{R}_{ij}$  = the interest rate at time  $i$  for Eurocurrency  $j$ , for  $i = (0,1)$  and  $j = (1, \dots, n)$ . This random variable is non-stochastic at time 0 but stochastic at time 1.

$\tilde{R}_i$  = the CD (or Eurodollar) deposit rate at time  $i$ , for  $i = (0,1)$ . This random variable is non-stochastic at time 0 but stochastic at time 1.

$P_t^f, \tilde{P}_t^f$  = the rate for interest rate futures contract at time 0 and at time 1, respectively. This random variable is non-stochastic at time 0 but stochastic at time 1.

$\tilde{Q}_t^j$  = the currency futures rate at time  $i$  for currency  $j$ , for  $i = (0,1,2)$  and  $j = (1, \dots, n)$ . This rate is expressed in units of U.S. dollar per one unit of foreign currency  $j$  and is non-stochastic at time 0 and stochastic at other times.

$f$  = the quantity of interest rate futures contracts that the bank establishes at time 0. This is a decision variable and  $f > 0$  corresponds to a long position and  $f < 0$  corresponds to a short position.

$F_{0j}, F_{1j}$  = the quantity of currency futures contracts for foreign currency  $j$  that the bank establishes at time 0 and at time 1, respectively, for  $j = (1, \dots, n)$ . These are all decision variables and  $F_{0j} > 0$  and  $F_{1j} > 0$  correspond to long positions and  $F_{0j} < 0$  and  $F_{1j} < 0$  correspond to short positions.

The balance sheet constraint at time 0 is

$$L + \sum_{j=1}^n C_{0j} S_{0j} = D_0 + K_0 \quad (1.1)$$

, where  $\sum_{j=1}^n C_{0j} S_{0j}$  = the net foreign currency assets.

During the first period, profits are obtained from the interest payment from loans plus the return from holding foreign currencies plus any gains or losses in the interest rate and currency futures markets less the costs of deposits. The return from holding a foreign currency  $j$  is the interest rate for the currency and period considered plus any exchange rate variation [See, Levy (1981) and Grammatikos, Saunders, and Swary (1986)]. Suppose that a bank is currently holding foreign currency  $j$ . After one holding period, the bank converts back to U.S. dollar and receives  $C_{0j} \tilde{S}_{1j}$ . Thus, the holding period return from exchange rate fluctuations is  $C_{0j} (\tilde{S}_{1j} - S_{0j})$ , which is called exchange rate capital gains return. The investment of the foreign currency  $j$  will grow by  $C_{0j} R_{0j}^*$  during the period (in terms of the foreign currency  $j$ ). When the bank converts this end-of-period amount into U.S. dollars at the exchange rate  $\tilde{S}_{1j}$ , it receives  $C_{0j} R_{0j}^* \tilde{S}_{1j}$ . The sum of the exchange rate capital gains return,  $C_{0j} (\tilde{S}_{1j} - S_{0j})$ , and the currency  $j$  in-

terest payment for the holding period,  $C_{0j} R_{0j}^* \tilde{S}_{1j}$ , is the total return from holding foreign currencies in period 1, i.e.,  $[C_{0j} (1 + R_{0j}^*) \tilde{S}_{1j} - C_{0j} S_{0j}]$ . It follows, therefore, that the profit function for period 1 can be written as

$$\begin{aligned} \tilde{\Pi}_1 = & LR_L + \sum_{j=1}^n \{C_{0j} [(1 + R_{0j}^*) \tilde{S}_{1j} - S_{0j}]\} - D_0 R_0 \\ & + (\tilde{P}_1^f - P_0^f) f + \sum_{j=1}^n (\tilde{Q}_{1j}^f - Q_{0j}^f) F_{0j} \end{aligned} \quad (1.2)$$

The balance sheet constraint, (1.1), can be used to express  $D_0$  in terms of other quantities.

$$D_0 = L + \sum_{j=1}^n C_{0j} S_{0j} - K_0 \quad (1.3)$$

Substituting (1.3) back into (1.2), we obtain

$$\begin{aligned} \tilde{\Pi}_1 = & L(R_L - R_0) + \sum_{j=1}^n \{C_{0j} [(1 + R_{0j}^*) \tilde{S}_{1j} - (1 + R_0) S_{0j}]\} \\ & + K_0 R_0 + (\tilde{P}_1^f - P_0^f) f + \sum_{j=1}^n (\tilde{Q}_{1j}^f - Q_{0j}^f) F_{0j} \end{aligned} \quad (1.4)$$

This first-period profit function that reflects balance sheet risks is determined by the bank's net interest revenue (net of deposit costs) plus the stochastic return from holding foreign currencies subject to foreign exchange rate risk plus savings in the costs of de-

posits due to holding capital plus any stochastic gains or losses in the interest rate and currency futures markets. In the absence of futures trading, the only direct uncertainty in period 1 is the exchange risk on the foreign currency net investment. However, as shown below, the decision on  $L$  establishes the maturity mismatch on domestic currency loan financing and creates uncertainty about interest rate spreads for the second period that will be resolved at the start of the second period. Thus interest rate futures contracts are entered at time 0 to hedge the interest rate risk in the second period.

At time 1, the bank takes another net position in foreign currencies which can be different, in size, from the time 0 net position in foreign currencies. The profits generated in the first period are carried over to the second period in the form of retained earnings, i.e., are not paid out as dividends. Therefore, the balance sheet constraint at time 1 is

$$L + \sum_{j=1}^n C_{1j} \tilde{S}_{1j} = D_1 + \tilde{K}_1 \quad (1.5)$$

, where  $\tilde{K}_1 \equiv \tilde{\Pi}_1 + K_0$ .

Following the same line of reasoning as the profit generating process of the first period, the second period profits are obtained from the interest payment from loans plus the stochastic return from holding foreign currencies plus any stochastic gains or losses in the currency futures market less the costs of deposits. The profit function for period 2 is, therefore,

$$\tilde{\Pi}_2 = LR_L + \sum_{j=1}^n \{C_{1j} [(1 + \tilde{R}_{1j}^*) \tilde{S}_{2j} - \tilde{S}_{1j}]\} - D_1 \tilde{R}_1$$

$$+ \sum_{j=1}^n (\tilde{Q}_{2j}^f - \tilde{Q}_{1j}^f) F_{1j} \quad (1.6)$$

The balance sheet constraint, (1.5), is used to express  $D_1$  in terms of other quantities.

$$D_1 = L + \sum_{j=1}^n C_{1j} \tilde{S}_{1j} - \tilde{K}_1 \quad (1.7)$$

Substituting (1.7) back into (1.6), we obtain

$$\begin{aligned} \tilde{\Pi}_2 = & L(R_L - \tilde{R}_1) + \sum_{j=1}^n \{C_{1j} [(1 + \tilde{R}_{1j}^*) \tilde{S}_{2j} - (1 + \tilde{R}_1) \tilde{S}_{1j}]\} \\ & + \tilde{K}_1 \tilde{R}_1 + \sum_{j=1}^n (\tilde{Q}_{2j}^f - \tilde{Q}_{1j}^f) F_{1j} \end{aligned} \quad (1.8)$$

Terminal wealth at time 2 less initial wealth at time 0 equals the first period profits plus the second period profits that include reinvestment opportunities for cash flows (i.e., the "future value" of the cash flows) generated in the first period. That is,

$$\tilde{\Pi} = \tilde{\Pi}_1 + \tilde{\Pi}_2 \quad \text{or}$$

$$\tilde{\Pi} = K_0 \tilde{\tau} + L \tilde{R}_l + \sum_{j=1}^n C_{0j} \tilde{R}_{c0j} + \sum_{j=1}^n C_{1j} \tilde{R}_{c1j} + f \tilde{R}_f$$

$$+ \sum_{j=1}^n F_{0j} \tilde{R}_{F0j} + \sum_{j=1}^n F_{1j} \tilde{R}_{F1j} \quad (1.9)$$

, where

$$\tilde{\tau} = R_0 + (1 + R_0) \tilde{R}_1 ,$$

$$\tilde{R}_l = [(R_L - R_0) + (R_L - \tilde{R}_1) + (R_L - R_0) \tilde{R}_1] ,$$

$$\tilde{R}_{coj} = (1 + \tilde{R}_1) [(1 + R_{0j}^*) \tilde{S}_{1j} - (1 + R_0) S_{0j}] ,$$

$$\tilde{R}_{c1j} = [(1 + \tilde{R}_{1j}^*) \tilde{S}_{2j} - (1 + \tilde{R}_1) \tilde{S}_{1j}] ,$$

$$\tilde{R}_f = (1 + \tilde{R}_1) (\tilde{P}_1^f - P_0^f) ,$$

$$\tilde{R}_{F0j} = (1 + \tilde{R}_1) (\tilde{Q}_{1j}^f - Q_{0j}^f) ,$$

$$\tilde{R}_{F1j} = (\tilde{Q}_{2j}^f - Q_{1j}^f) .$$

Interpretations for these variables can be made as follows:

$\tilde{\tau}$  = the deposit cost savings per unit capital for both periods.

$\tilde{R}_l$  = the net interest revenue (net of deposit costs) per unit loan for both periods.

This variable reflects the maturity mismatch problem as well as reinvestment opportunities in the second period for net loan revenue generated in the first period.

$\tilde{R}_{c0j}$  = the terminal value of the holding-period return on foreign currency j for the first period that includes reinvestment opportunities at the random rate prevailing in the second period.

$\tilde{R}_{c1j}$  = the holding-period return on foreign currency j for the second period.

$\tilde{R}_f$  = the terminal value of the return from trading interest rate futures contracts for the first period that includes reinvestment opportunities at the random rate prevailing in the second period.

$\tilde{R}_{f0j}$  = the terminal value of the return from trading jth foreign currency futures contract for the first period that includes reinvestment opportunities at the random rate prevailing in the second period.

$\tilde{R}_{f1j}$  = the return from trading jth foreign currency futures contract for the second period.

## Chapter 3

# OPTIMAL SPOT AND FUTURES POSITIONS

The (terminal) profit function, (1.9), can be compactly written using vector notation as follows:

$$\tilde{\Pi} = K_0 \tilde{\tau} + L \tilde{R}_l + f \tilde{R}_f + C'_0 \tilde{R}_{c0} + C'_1 \tilde{R}_{c1} + F'_0 \tilde{R}_{F0} + F'_1 \tilde{R}_{F1} \quad (2.1)$$

, where

$$\tilde{\tau} = R_0 + (1 + R_0) \tilde{R}_1 ,$$

$$\tilde{R}_l = [(R_L - R_0) + (R_L - \tilde{R}_1) + (R_L - R_0) \tilde{R}_1] ,$$

$$\tilde{R}_f = (1 + \tilde{R}_1) (\tilde{P}_1^f - P_0^f) ,$$

$$C'_0 = [C_{01} \ C_{02} \ C_{03} \ \dots \ C_{0n}] ,$$

$$C'_1 = [C_{11} \ C_{12} \ C_{13} \ \dots \ C_{1n}] ,$$

$$\mathbf{F}'_0 = [F_{01} \ F_{02} \ F_{03} \ \dots \ F_{0n}] \ ,$$

$$\mathbf{F}'_1 = [F_{11} \ F_{12} \ F_{13} \ \dots \ F_{1n}] \ ,$$

$$\tilde{\mathbf{R}}_{c0} = (1 + \tilde{R}_1) \begin{bmatrix} (1 + R_{01}^*) \tilde{S}_{11} - (1 + R_0) S_{01} \\ (1 + R_{02}^*) \tilde{S}_{12} - (1 + R_0) S_{02} \\ \bullet \\ \bullet \\ \bullet \\ (1 + R_{0n}^*) \tilde{S}_{1n} - (1 + R_0) S_{0n} \end{bmatrix} \ ,$$

$$\tilde{\mathbf{R}}_{c1} = \begin{bmatrix} (1 + \tilde{R}_{11}^*) \tilde{S}_{21} - (1 + \tilde{R}_1) \tilde{S}_{11} \\ (1 + \tilde{R}_{12}^*) \tilde{S}_{22} - (1 + \tilde{R}_1) \tilde{S}_{12} \\ \bullet \\ \bullet \\ \bullet \\ (1 + \tilde{R}_{1n}^*) \tilde{S}_{2n} - (1 + \tilde{R}_1) \tilde{S}_{1n} \end{bmatrix} \ ,$$

$$\tilde{\mathbf{R}}_{F0} = (1 + \tilde{R}_1) \begin{bmatrix} \tilde{Q}_{11}^f - Q_{01}^f \\ \tilde{Q}_{12}^f - Q_{02}^f \\ \bullet \\ \bullet \\ \bullet \\ \bullet \\ \tilde{Q}_{1n}^f - Q_{0n}^f \end{bmatrix}, \quad \tilde{\mathbf{R}}_{F1} = \begin{bmatrix} \tilde{Q}_{21}^f - \tilde{Q}_{11}^f \\ \tilde{Q}_{22}^f - \tilde{Q}_{12}^f \\ \bullet \\ \bullet \\ \bullet \\ \bullet \\ \tilde{Q}_{2n}^f - \tilde{Q}_{1n}^f \end{bmatrix}.$$

There is no conclusive agreement among economists on the choice of bank objective function. Two divergent views co-existed: risk-neutral and risk-averse objective function. The risk-neutral objective function is appropriate when the bank's choice set is a subset of the shareholder's overall opportunity set in perfect markets [See Santomero (1984)]. In this case, the shareholders can be viewed as optimizing this subset, given that their other personal wealth allocations remain constant. Accordingly, the shareholders can be assured an efficient allocation without regard to the risk level that may be hedged elsewhere in their overall portfolio. As Santomero (1984) adds, "this is particularly true in a perfect capital market where financial intermediaries need not exist and the investor's opportunity set spans the institution's choice. Accordingly, any efficient bank portfolio can be perfectly duplicated or hedged by the investor." Thus use of a risk neutral objective involves an inherent contradiction: the objective is only appropriate when these firms could not exist. This contradiction is important for financial institutions because the bank's existence depends on its ability to exploit financial market opportunities that are not available to the shareholders, i.e., to operate in imperfect financial markets. The argument offered in favor of a risk-averse objective function employs traditional corporate finance theory as its basic foundation. Management of the

banking firm is responsible for decision making and is unable to diversify risks specific to its claims on the bank [See, Santomero (1984) and Smith & Stulz (1985)]. Given this assumption, the agency problems (between management and shareholders) introduced into a managerial compensation scheme that is tied to the bank's payoffs provide an impetus for bank management to focus on the marginal rate of substitution between total risk and return. Furthermore, even in the absence of traditional agency problems, bank regulation in the forms of regulatory interference and chartering restrictions imposes costs on bank managers that shareholders do not fully incur. That creates a further lack of diversification for managers and an increased emphasis on total risk exposure. (Systematic risk exposure is not the relevant variable here). In this situation, maximization of managers' expected utility of the bank's terminal payoffs is generally assumed appropriate for the objective function of the banking firm [See Santomero (1984)].

Accordingly, in this model, bank management selects  $L$ ,  $C_0$ ,  $C_1$ ,  $f$ ,  $F_0$ , and  $F_1$  so as to maximize its expected utility function defined over terminal profits. The utility function is assumed to be continuous, concave, and a differentiable function with  $U'(\tilde{\Pi}) > 0$  and  $U''(\tilde{\Pi}) < 0$ .

Bank management's objective can be represented as

$$\text{MAX}_{L, C_0, C_1, f, F_0, F_1} \quad EU(\tilde{\Pi}) .$$

### 3.1 Optimal Foreign Currency Assets and Futures Positions at Time 1

We will solve this problem using the backward recursive procedure of dynamic programming adopted by Baesel and Grant (1982) and Morgan and Smith (1987). This backward procedure is set up such that the computations for optimal solutions start in the second period and then proceed backward to the first period.<sup>4</sup> Recognizing the backward procedure of dynamic programming, bank management selects  $C_1$  and  $F_1$  at time 1, given  $L$ ,  $C_0$ ,  $f$ , and  $F_0$ . It follows, therefore, that bank management's objective at time 1 can be represented as:

$$\text{MAX}_{C_1, F_1} E_1 U(\tilde{\Pi}) ,$$

where  $E_1$  is the expectations operator at time 1 conditional on  $L$ ,  $C_0$ ,  $f$ ,  $F_0$ .

The first order conditions are provided below.

$$E_1[ U'(\tilde{\Pi}) \tilde{R}_{c1} ] = 0 \tag{2.2}$$

$$E_1[ U'(\tilde{\Pi}) \tilde{R}_{F1} ] = 0 \tag{2.3}$$

Before proceeding with the derivation of optimal positions, we seek to derive the interest rate parity theorem under uncertainty using those first order conditions.

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<sup>4</sup> Taha (1987) presents the procedure associated with the dynamic programming algorithm. In dynamic programming, computations for optimal solutions are carried out in periods by breaking down the problem into subproblems. Each subproblem is then considered separately with the objective. However, since the subproblems are interdependent, we link the computations in a manner that guarantees that optimal solutions for each period are also feasible for the entire problem.

**Proposition 1.** (covered interest rate parity theorem under uncertainty): For any pair of domestic CD (or Eurodollar) deposit and Eurocurrency deposit, a no arbitrage condition on foreign exchange operations holds that the domestic CD (or Eurodollar) interest rate will equal the Eurocurrency interest rate covered in the currency futures market, if currency futures contracts that are entered at time 1 expire at time 2.

*proof.* To prove this proposition, we substitute the original definitions of  $\mathbf{R}_{c1}$  and  $\mathbf{R}_{f1}$  back into (2.2) and (2.3), considering the case of a single foreign currency. Notice that when new information with regard to  $\tilde{R}_1$ ,  $\tilde{R}_{1j}^*$ ,  $\tilde{S}_{1j}$ , and  $\tilde{Q}_{1j}^f$  is received by the bank at time 1, those random variables become non-stochastic at time 1. It follows, therefore, that

$$E_1 \{U'(\tilde{\Pi}) [(1 + R_{1j}^*) \tilde{S}_{2j} - (1 + R_1) S_{1j}]\} = 0 \quad (2.2a)$$

$$E_1 [U'(\tilde{\Pi}) (\tilde{Q}_{2j}^f - Q_{1j}^f)] = 0 \quad (2.3a)$$

If currency futures contracts expire at time 2 so that  $\tilde{Q}_{2j}^f$  equals  $\tilde{S}_{2j}$ , then equation (2.3a) becomes

$$E_1 [U'(\tilde{\Pi}) (\tilde{S}_{2j} - Q_{1j}^f)] = 0 \quad (2.3b)$$

From (2.2a) and (2.3b), we obtain

$$(1 + R_{1j}^*) E_1 [U'(\tilde{\Pi}) \tilde{S}_{2j}] - (1 + R_1) S_{1j} E_1 [U'(\tilde{\Pi})] = 0 \quad (2.2b)$$

$$E_1 [U'(\tilde{\Pi}) \tilde{S}_{2j}] - Q_{1j}^f E_1 [U'(\tilde{\Pi})] = 0 \quad (2.3c)$$

Solving (2.2b) and (2.3c) simultaneously, we obtain the following relationship:

$$\frac{1 + R_1}{1 + R_{1j}^*} = \frac{Q_{1j}^f}{S_{1j}} \quad \text{for any } j = (1, \dots, n) ,$$

which is exactly the same as the interest rate parity theorem. Note that it is shown by Cox, Ingersoll, and Ross (1981) that with a constant interest rate, the forward rate equals the futures rate at any time.

We now assume that terminal profits and each random vector are jointly normally distributed and bank management's utility function is characterized by constant absolute risk aversion.

Referring back to the first order conditions, we can expand (2.2) and (2.3) by rearranging the definition of covariance, i.e.,  $E(xy) = E(x)E(y) + cov(x, y)$ .

$$E_1 [ U'(\tilde{\Pi}) ] E_1 (\tilde{\mathbf{R}}_{c1}) + cov [ U'(\tilde{\Pi}), \tilde{\mathbf{R}}_{c1} ] = \mathbf{0} \quad (2.2.1)$$

$$E_1 [ U'(\tilde{\Pi}) ] E_1 (\tilde{\mathbf{R}}_{F1}) + cov [ U'(\tilde{\Pi}), \tilde{\mathbf{R}}_{F1} ] = \mathbf{0} . \quad (2.3.1)$$

It is shown by Rubinstein (1976) that if  $\tilde{x}$  and  $\tilde{y}$  are jointly normal and  $g(\tilde{y})$  is any at least once differentiable function of  $\tilde{y}$ , then

$$cov[\tilde{x}, g(\tilde{y})] = E[g'(\tilde{y})] cov(\tilde{x}, \tilde{y}).$$

Using this result, we can rewrite (2.2.1) and (2.3.1) as

$$E_1 [ U'(\tilde{\Pi}) ] E_1 (\tilde{\mathbf{R}}_{c1}) + E_1 [ U''(\tilde{\Pi}) ] cov(\tilde{\Pi}, \tilde{\mathbf{R}}_{c1}) = \mathbf{0} \quad (2.2.1a)$$

$$E_1 [ U'(\tilde{\Pi}) ] E_1 (\tilde{\mathbf{R}}_{F1}) + E_1 [ U''(\tilde{\Pi}) ] cov(\tilde{\Pi}, \tilde{\mathbf{R}}_{F1}) = \mathbf{0} \quad (2.3.1a)$$

These equations can be rewritten by dividing each equation by  $E_1[U'(\tilde{\Pi})] > 0$  as

$$E_1(\tilde{\mathbf{R}}_{c1}) - \chi \text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{c1}) = \mathbf{0} \quad (2.4)$$

$$E_1(\tilde{\mathbf{R}}_{F1}) - \chi \text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{F1}) = \mathbf{0} \quad (2.5)$$

, where  $\chi = -\frac{E_1[U''(\tilde{\Pi})]}{E_1[U'(\tilde{\Pi})]}$ . That is,  $\chi$  is a constant absolute risk aversion parameter.

It can be shown that

$$\text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{c1}) = \text{var}(\tilde{\mathbf{R}}_{c1}) \mathbf{C}_1 + \text{cov}(\tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1}) \mathbf{F}_1$$

$$\text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{F1}) = \text{cov}(\tilde{\mathbf{R}}_{F1}, \tilde{\mathbf{R}}_{c1}) \mathbf{C}_1 + \text{var}(\tilde{\mathbf{R}}_{F1}) \mathbf{F}_1 .$$

Substituting these equations into (2.4) and (2.5) gives

$$E_1(\tilde{\mathbf{R}}_{c1}) - \chi [\text{var}(\tilde{\mathbf{R}}_{c1}) \mathbf{C}_1 + \text{cov}(\tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1}) \mathbf{F}_1] = \mathbf{0} \quad (2.4.1)$$

$$E_1(\tilde{\mathbf{R}}_{F1}) - \chi [\text{cov}(\tilde{\mathbf{R}}_{F1}, \tilde{\mathbf{R}}_{c1}) \mathbf{C}_1 + \text{var}(\tilde{\mathbf{R}}_{F1}) \mathbf{F}_1] = \mathbf{0} \quad (2.5.1)$$

From (2.5.1) we can derive optimal currency futures contracting at time 1, given  $\mathbf{C}_1$ .

$$\mathbf{F}_1^* = \frac{1}{\chi} [\text{var}(\tilde{\mathbf{R}}_{F1})]^{-1} E_1(\tilde{\mathbf{R}}_{F1}) - [\text{var}(\tilde{\mathbf{R}}_{F1})]^{-1} \text{cov}(\tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1}) \mathbf{C}_1 \quad (2.6)$$

or

$$\mathbf{F}_1^* = \frac{1}{\chi} [\text{var}(\tilde{\mathbf{Q}}_2^f)]^{-1} E_1(\tilde{\mathbf{R}}_{F1}) - [\text{var}(\tilde{\mathbf{Q}}_2^f)]^{-1} \text{cov}[\tilde{\mathbf{Q}}_2^f, (1 + \mathbf{R}_1^*) \tilde{\mathbf{S}}_2] \mathbf{C}_1, \quad (2.6a)$$

where

$\tilde{\mathbf{Q}}_1^c = (n \times 1)$  currency futures rate vector.

$(1 + \mathbf{R}_i^c) \tilde{\mathbf{S}}_2 = (n \times 1)$  return vector on per unit Eurocurrency deposit as converted back to domestic currency at time 2.

This result says that if currency futures rates at time 1 were unbiased estimates of expected currency futures rates at time 2, i.e.,  $E_1(\tilde{\mathbf{R}}_{F1}) = \mathbf{0}$  — we call this unbiasedness of currency futures rates — then the optimal hedge ratios for net foreign currency asset position at time 1 are given by the product of the slope coefficient matrix of the *multivariate* regressions of period 2's vector of returns on Eurocurrency deposits (converted to the domestic currency value) on time 2 currency futures rates vector. Suppose that  $E_1(\mathbf{R}_{c1}) = \mathbf{0}$ . This is true if IRP holds and time 1 currency futures (forward) rates could be considered unbiased estimates of future (time 2) spot exchange rates — we call this a pure expectation hypothesis. Then, the bank that maximizes expected utility of profits will have an incentive to take advantage of the profit opportunities perceived in the currency futures market and will not take net asset positions in foreign currencies at time 1. If unbiasedness of currency futures rates, the pure expectation hypothesis, and IRP hold, the bank will, as shown below, never take positive or negative net asset positions in foreign currencies, i.e.,  $\mathbf{C}_1^c = \mathbf{0}$ , which will, in turn, dismiss the bank from entering into currency futures contracts, i.e.,  $\mathbf{F}_1^c = \mathbf{0}$ . This is because the bank can implement hedging internally by balancing foreign currency asset and liability positions and because no profit opportunity exists in the currency futures market.

Substituting (2.6) into (2.4.1) gives optimal net position in foreign currency assets at time 1, given that futures positions are adjusted optimally as net currency asset positions vary.

$$C_1^* = \frac{1}{\chi} \Sigma_{11.2}^{-1} \alpha_2 , \quad (2.7)$$

where

$$\Sigma_{11.2} = \text{var}(\tilde{\mathbf{R}}_{c1}) - \text{cov}(\tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1}) [\text{var}(\tilde{\mathbf{R}}_{F1})]^{-1} \text{cov}(\tilde{\mathbf{R}}_{F1}, \tilde{\mathbf{R}}_{c1}) ,$$

$$\alpha_2 = E_1(\tilde{\mathbf{R}}_{c1}) - \text{cov}(\tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1}) [\text{var}(\tilde{\mathbf{R}}_{F1})]^{-1} E_1(\tilde{\mathbf{R}}_{F1}) .$$

$\Sigma_{11.2}$  is  $(n \times n)$  nonsingular matrix and  $\alpha_2$  is  $(n \times 1)$  vector. To facilitate the analysis, we define

$$\tilde{\mathbf{R}}_2 = \begin{bmatrix} \tilde{\mathbf{R}}_{c1} \\ \tilde{\mathbf{R}}_{F1} \end{bmatrix} , \quad \Sigma_2 = \begin{bmatrix} \text{var}(\tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{\mathbf{R}}_{F1}, \tilde{\mathbf{R}}_{c1}) \\ \text{cov}(\tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1}) & \text{var}(\tilde{\mathbf{R}}_{F1}) \end{bmatrix}$$

$\tilde{\mathbf{R}}_2$  is  $(2n \times 1)$  return vector and  $\Sigma_2$  is  $(2n \times 2n)$  matrix with full rank of  $2n$ . Suppose that  $\tilde{\mathbf{R}}_2$  is *multivariate* normal with mean vector,  $E_1(\tilde{\mathbf{R}}_2)$ , and variance-covariance matrix,  $\Sigma_2$ . Then,  $\alpha_2$  is simply the vector of constants (intercepts) from the *multivariate* regressions of  $\tilde{\mathbf{R}}_{c1}$  on  $\tilde{\mathbf{R}}_{F1}$  and  $\Sigma_{11.2}$  is residual variance-covariance matrix from the *multivariate* regressions of  $\tilde{\mathbf{R}}_{c1}$  on  $\tilde{\mathbf{R}}_{F1}$ . Consequently, the optimal net position in foreign currencies at time 1 — given that futures positions are adjusted optimally as net currency asset positions vary — is simply represented by the product of the inverse of the risk aversion index times the ratio of constant terms to residual variances in the *multivariate* regressions of the currency spot return on the currency futures return.

### 3.2 Optimal Spot and Futures Positions at Time 0

To determine the optimal decision at time 0, we substitute  $C_1$  and  $F_1$  into (2.1) and maximize expected utility with  $L$ ,  $C_0$ ,  $f$ , and  $F_0$  as decision variables. However, at time 0 when bank management makes decisions with regard to the choice variables, it does not know the values of  $C_1$  and  $F_1$ . We will follow the simplifying assumption of Baesel and Grant (1982) that bank managers employ expectations of  $C_1$  and  $F_1$  at time 0. We therefore write period 1 profit function as

$$\tilde{\Pi} = K_0 \tilde{\tau} + L \tilde{R}_l + f \tilde{R}_f + C_0' \tilde{R}_{c0} + F_0' \tilde{R}_{f0} + E(\tilde{C}_1^*) \tilde{R}_{c1} + E(\tilde{F}_1^*) \tilde{R}_{f1} , \quad (2.1.1)$$

where  $E$  is the expectations operator at time 0.

Bank management's objective at time 0 can be represented as

$$\text{MAX}_{L, C_0, f, F_0} \quad EU(\tilde{\Pi}) .$$

The first order conditions are provided below.

$$E [ U'(\tilde{\Pi}) \tilde{R}_l ] = 0 \quad (2.8)$$

$$E [ U'(\tilde{\Pi}) \tilde{R}_{c0} ] = 0 \quad (2.9)$$

$$E [ U'(\tilde{\Pi}) \tilde{R}_f ] = 0 \quad (2.10)$$

$$E [ U'(\tilde{\Pi}) \tilde{R}_{f0} ] = 0 \quad (2.11)$$

By exactly parallel reasoning that we have followed earlier, these first order conditions can be rewritten as

$$E(\tilde{R}_l) - \chi \text{cov}(\tilde{\Pi}, \tilde{R}_l) = 0 \quad (2.8.1)$$

$$E(\tilde{\mathbf{R}}_{c0}) - \chi \text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{c0}) = \mathbf{0} \quad (2.9.1)$$

$$E(\tilde{R}_f) - \chi \text{cov}(\tilde{\Pi}, \tilde{R}_f) = 0 \quad (2.10.1)$$

$$E(\tilde{\mathbf{R}}_{F0}) - \chi \text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{F0}) = \mathbf{0} \quad (2.11.1)$$

All covariance terms are shown in Appendix in terms of covariances among and variances of relevant random vectors (or variables). From the Appendix, we define

$$\Sigma_1 = \begin{bmatrix} \text{var}(\tilde{R}_l) & \text{cov}(\tilde{R}_l, \tilde{\mathbf{R}}_{c0}) & \text{cov}(\tilde{R}_l, \tilde{R}_f) & \text{cov}(\tilde{R}_l, \tilde{\mathbf{R}}_{F0}) \\ \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{R}_l) & \text{var}(\tilde{\mathbf{R}}_{c0}) & \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{R}_f) & \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{F0}) \\ \text{cov}(\tilde{R}_f, \tilde{R}_l) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c0}) & \text{var}(\tilde{R}_f) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F0}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_l) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c0}) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_f) & \text{var}(\tilde{\mathbf{R}}_{F0}) \end{bmatrix}.$$

We assume that  $\Sigma_1$  is a  $(2n + 2) \times (2n + 2)$  nonsingular matrix.

Partitioned matrix of  $\Sigma_1$  is given by

$$\Sigma_1 = \begin{bmatrix} \Sigma_{00} & \Sigma_{01} \\ \Sigma_{10} & \Sigma_{11} \end{bmatrix}$$

, where

$$\Sigma_{00} = \begin{bmatrix} \text{var}(\tilde{R}_I) & \text{cov}(\tilde{R}_I, \tilde{\mathbf{R}}_{c0}) \\ \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{R}_I) & \text{var}(\tilde{\mathbf{R}}_{c0}) \end{bmatrix}, \quad \Sigma_{01} = \begin{bmatrix} \text{cov}(\tilde{R}_I, \tilde{R}_f) & \text{cov}(\tilde{R}_I, \tilde{\mathbf{R}}_{F0}) \\ \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{R}_f) & \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{F0}) \end{bmatrix},$$

$$\Sigma_{10} = \begin{bmatrix} \text{cov}(\tilde{R}_f, \tilde{R}_I) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c0}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_I) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c0}) \end{bmatrix}, \quad \Sigma_{11} = \begin{bmatrix} \text{var}(\tilde{R}_f) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F0}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_f) & \text{var}(\tilde{\mathbf{R}}_{F0}) \end{bmatrix}.$$

All of these matrices have the dimension of  $(n + 1) \times (n + 1)$ .

In addition, we define

$$\Sigma_{02} = \begin{bmatrix} \text{cov}(\tilde{R}_I, \tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{R}_I, \tilde{\mathbf{R}}_{F1}) \\ \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{F1}) \end{bmatrix}, \quad \Sigma_{12} = \begin{bmatrix} \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F1}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{F1}) \end{bmatrix}.$$

These matrices have the dimension of  $(n + 1) \times 2n$ .

Define

$$\tilde{\mathbf{m}}_c = \begin{bmatrix} \tilde{R}_I \\ \tilde{\mathbf{R}}_{c0} \end{bmatrix}, \quad \tilde{\mathbf{m}}_f = \begin{bmatrix} \tilde{R}_f \\ \tilde{\mathbf{R}}_{F0} \end{bmatrix},$$

$$\mathbf{q}_c = \begin{bmatrix} \text{cov}(\tilde{R}_I, \tilde{\tau}) \\ \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\tau}) \end{bmatrix}, \quad \mathbf{q}_f = \begin{bmatrix} \text{cov}(\tilde{R}_f, \tilde{\tau}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\tau}) \end{bmatrix},$$

where  $\tilde{\mathbf{m}}_c$  is  $(n + 1) \times 1$  asset return vector,  $\tilde{\mathbf{m}}_f$  is  $(n + 1) \times 1$  futures return vector,  $\mathbf{q}_c$  and  $\mathbf{q}_f$  are each  $(n + 1) \times 1$  covariance vector.

Then, equations (2.8.1) and (2.9.1) can be combined to be rewritten in matrix notation as follows:

$$E(\tilde{\mathbf{m}}_c) - \chi [\Sigma_{00} \mathbf{y} + \Sigma_{01} \mathbf{g} + \Sigma_{02} E(\tilde{\mathbf{p}}_2^*) + \mathbf{q}_c K_0] = \mathbf{0} \quad (2.12)$$

, where

$$\mathbf{y} = \begin{bmatrix} L \\ \mathbf{C}_0 \end{bmatrix}, \quad \mathbf{g} = \begin{bmatrix} f \\ \mathbf{F}_0 \end{bmatrix}, \quad \tilde{\mathbf{p}}_2^* = \begin{bmatrix} \tilde{\mathbf{C}}_1^* \\ \tilde{\mathbf{F}}_1^* \end{bmatrix}.$$

$\mathbf{y}$  is  $(n + 1) \times 1$  decision vector at time 0 for loan extensions and net foreign currency asset positions.  $\mathbf{g}$  is  $(n + 1) \times 1$  optimal futures decision vector at time 0 for interest rate and currency futures positions.  $\tilde{\mathbf{p}}_2^*$  is  $(2n) \times 1$  decision vector at time 1 for (spot) foreign currency positions and currency futures positions.

Also, equations (2.10.1) and (2.11.1) can be combined to be rewritten as

$$E(\tilde{\mathbf{m}}_f) - \chi [\Sigma_{10} \mathbf{y} + \Sigma_{11} \mathbf{g} + \Sigma_{12} E(\tilde{\mathbf{p}}_2^*) + \mathbf{q}_f K_0] = \mathbf{0} \quad (2.13)$$

Suppose that the bank currently makes loans,  $L$ , and takes net asset position in foreign currencies,  $\mathbf{C}_0$ . In this situation, the optimal futures position vectors that satisfy the equation (2.13) can be uniquely determined if and only if  $\Sigma_{11}$  is nonsingular.

Solving for  $\mathbf{g}$  in equation (2.13), we obtain

$$\mathbf{g}^* = \frac{1}{\chi} \Sigma_{11}^{-1} E(\tilde{\mathbf{m}}_f) - \Sigma_{11}^{-1} \Sigma_{10} \mathbf{y} - \Sigma_{11}^{-1} \Sigma_{12} E(\tilde{\mathbf{p}}_2^*) - \Sigma_{11}^{-1} \mathbf{q}_f K_0 \quad (2.14)$$

, where  $\mathbf{g}^* = \begin{bmatrix} f^* \\ \mathbf{F}_0^* \end{bmatrix}$ .

or

$$\begin{aligned}
\begin{bmatrix} f^* \\ \mathbf{F}_0^* \end{bmatrix} &= \frac{1}{\lambda} \Sigma_{11}^{-1} \begin{bmatrix} E(\tilde{R}_f) \\ E(\tilde{\mathbf{R}}_{F0}) \end{bmatrix} - \Sigma_{11}^{-1} \Sigma_{10} \begin{bmatrix} L \\ \mathbf{C}_0 \end{bmatrix} \\
&\quad - \Sigma_{11}^{-1} \Sigma_{12} \begin{bmatrix} E(\tilde{\mathbf{C}}_1^*) \\ E(\tilde{\mathbf{F}}_1^*) \end{bmatrix} - \Sigma_{11}^{-1} \begin{bmatrix} cov(\tilde{R}_f, \tilde{\tau}) \\ cov(\tilde{\mathbf{R}}_{F0}, \tilde{\tau}) \end{bmatrix} K_0
\end{aligned} \tag{2.14.1}$$

$\mathbf{g}^*$  is  $(n + 1) \times 1$  optimal interest rate and currency futures position vector for period 1.

Equation (2.14.1) characterizes the optimal positions at time 0 (given  $L$  and  $\mathbf{C}_0$ ) for interest rate futures,  $f^*$ , and currency futures,  $\mathbf{F}_0^*$ , respectively. This result says that the optimal futures positions at time 0 — given that the bank behaves optimally in extending loans and taking long positions in foreign currencies at time 0 — can be decomposed into the profit opportunities from trading futures contracts adjusted for the bank's risk aversion, the (spot) foreign currency trading flows, the loan extensions, the second period optimal currency spot and futures behavior, and the deposit cost savings due to holding capital. As expected, the optimal hedging decisions anticipated for time 1 influence time 0 decisions via covariances among the first period interest rate/currency futures return and the second period currency spot/futures return. The sign of  $\mathbf{g}^*$  in equation (2.14) can be positive or negative — that is, given loan extensions and given long positions in net foreign currency assets, the bank can take long or short positions in interest rate and currency futures contracts at time 0. The sign of  $\mathbf{g}^*$  in equation (2.14) depends on signs of expected profits from trading futures, covariances among return vectors on holding net currency asset positions, extending loans, and trading futures, covariances among the first period futures return and the second period currency spot/futures return, and covariances between deposit cost savings and the futures return vector.

It is worthwhile to note that  $E(\tilde{\mathbf{m}}_j)$  can not be zero even with the unbiasedness of currency futures rates. That is, unlike extant bank hedging literatures, the profit opportunities in futures markets do not vanish even though futures markets are martingale-efficient in removing excess profits. This is because reinvestment opportunities in the second period enable the bank to take advantage of any deviation of *ex post* first period futures return from *ex ante* zero expected futures return in the first period. This implies that the speculative component (as discussed below) of futures demand by the bank can explain one of the reasons why banks trade futures contracts at least over the long run.

The conventional decomposition of demand for futures positions categorizes the bank's futures demand into two components differentiated by motive: speculative demand and hedging demand. The first term of (2.14.1) captures the speculative demand, while the last three terms capture the hedging demand. (Note that a speculator has no spot position, i.e.,  $C_0 = C_1 = L = D = K = 0$ ). Suppose that the bank's participation in futures markets is not motivated by the speculative opportunities. Then, the optimal interest rate and currency futures positions at time 0 to hedge simultaneously both interest rate and exchange rate risks become

$$\mathbf{g}_h^* = -\Sigma_{11}^{-1} \Sigma_{10} \mathbf{y} - \Sigma_{11}^{-1} \Sigma_{12} E(\tilde{\mathbf{p}}_2^*) - \Sigma_{11}^{-1} \mathbf{q}_f K_0, \quad (2.15)$$

where

$\mathbf{g}_h^* = (n + 1) \times 1$  optimal interest rate/currency futures position vector at time 0 for the simultaneous hedge of loans subject to interest rate risk and of net foreign currency asset positions facing exchange rate risks.

The second term in equation (2.15) captures the anticipation of new information at time 1. This links the bank's optimal hedging behavior at time 0 to that at time 1. The last term captures the role of the second-period reinvestment opportunities in rendering deposit cost savings due to holding capital. Equation (2.15) suggests that time 0 optimal ratios for the simultaneous hedge against interest and exchange rate risks, given  $y$ ,  $E(\tilde{\mathbf{p}}_2)$ , and *multivariate* normality of relevant random vectors and/or variables, are provided by the coefficients of the *multivariate* regressions of  $\tilde{R}_1$  and  $\tilde{\mathbf{R}}_{e0}$  on  $\tilde{R}_f$  and  $\tilde{\mathbf{R}}_{F0}$ , and of  $\tilde{\mathbf{R}}_{e1}$  and  $\tilde{\mathbf{R}}_{F1}$  on  $\tilde{R}_f$  and  $\tilde{\mathbf{R}}_{F0}$ , and of the multiple regression of  $\tilde{\tau}$  on  $\tilde{R}_f$  and  $\tilde{\mathbf{R}}_{F0}$ .

$[\Sigma_{11}^{-1} \Sigma_{10}]$  is the  $(n + 1) \times (n + 1)$  matrix of *multivariate* regression coefficients. The first column of the matrix contains the coefficients relating the net interest revenue for both periods to the first period interest rate and currency futures return vectors, while the last  $n$  columns contain the coefficients relating the first period net foreign currency asset return vector to the first period interest rate and currency futures return vectors.  $[\Sigma_{11}^{-1} \Sigma_{12}]$  is a  $(n + 1) \times 2n$  matrix of another set of *multivariate* regression coefficients. The first  $n$  columns of the matrix contain the coefficients relating the second period return vector for net foreign currency asset position to the first period interest rate and currency futures return vectors, while the last  $n$  columns of the matrix contain the coefficients relating the second period currency futures return vector to the first period interest rate and currency futures return vectors.  $[\Sigma_{11}^{-1} \mathbf{q}_1]$  is the  $(n + 1) \times 1$  vector of multiple regression coefficients relating deposit cost savings (a function of capital) to the first period interest rate and currency futures return vectors.

Substituting (2.14) back into (2.12) and solving for  $y$  provides time 0 optimal decisions on loan extensions and net asset position in foreign currencies, given that time 0

interest rate and currency futures positions are adjusted optimally as decisions on loan extensions and net foreign currency asset positions vary.

$$\mathbf{y}^* = \frac{1}{\chi} \Sigma_{00.1}^{-1} \boldsymbol{\alpha}_1 - \Sigma_{00.1}^{-1} (\Sigma_{02} - \Sigma_{01} \Sigma_{11}^{-1} \Sigma_{12}) E(\tilde{\mathbf{p}}_2^*) - \Sigma_{00.1}^{-1} (\mathbf{q}_c - \Sigma_{01} \Sigma_{11}^{-1} \mathbf{q}_f) K_0, \quad (2.16)$$

where

$$\mathbf{y}^* = \begin{bmatrix} L^* \\ \mathbf{C}_0^* \end{bmatrix},$$

$$\Sigma_{00.1} = \Sigma_{00} - \Sigma_{01} \Sigma_{11}^{-1} \Sigma_{10},$$

$$\boldsymbol{\alpha}_1 = E(\tilde{\mathbf{m}}_c) - \Sigma_{01} \Sigma_{11}^{-1} E(\tilde{\mathbf{m}}_f).$$

$\Sigma_{00.1}$  is the  $(n + 1) \times (n + 1)$  population variance-covariance matrix conditional on  $\tilde{\mathbf{m}}_f = E(\tilde{\mathbf{m}}_f)$  and  $\boldsymbol{\alpha}_1$  is the  $(n + 1) \times 1$  vector of constants conditional on  $\tilde{\mathbf{m}}_f = E(\tilde{\mathbf{m}}_f)$ . Like time 0 optimal futures positions, time 0 optimal decisions on loan extensions and net asset positions in foreign currencies are affected by time 1 optimal currency spot and futures decisions.

### 3.3 An Analysis

In this section, we show that the separate hedging decision for a single period as it is modeled in most of the hedging literature is misleading. We also investigate the bank's intertemporal hedging behavior for optimal positions in foreign currencies and the role of IRP relationship in this regard.

Suppose that the bank does not consider time 1 decisions when it formulates time 0 decisions. Also, assume that the bank engages only in domestic banking activity by which we mean that a bank engages in accepting deposits, extending loans in its home currency, and participating in interest rate futures markets to hedge against interest rate risks. In this case, optimal interest rate futures position can be written from (2.15) as

$$f_{D0}^* = - \frac{\text{cov}(\tilde{R}_f, \tilde{R}_D)}{\text{var}(\tilde{R}_f)} L - \frac{\text{cov}(\tilde{R}_f, \tilde{\tau})}{\text{var}(\tilde{R}_f)} K_0 ,$$

where  $f_{D0}^*$  = the optimal interest rate futures position for domestic banking activity only.

This expression is exactly the same as that of minimum-variance hedging only with interest rate futures [See, Koppenhaver (1985) and Morgan, Shome, and Smith (1988)], which is the special case of our result. We suggest that this optimal interest rate futures position without the recognition of interdependence between interest and exchange rate risks could be misleading, as discussed later.

The investigation of the bank's intertemporal hedging of net asset positions in foreign currencies requires a comparison between the optimal currency futures positions of  $F_0^*$  at time 0 and  $F_1^*$  at time 1 when the resolution of uncertainty occurs. In order to compare the positions across periods,  $F_0^*$  should be obtained as if there were no interest rate risks (and thus non-existence of interest rate futures markets) and no reinvestment opportunities in period 2. These are characteristics of the second period decision. It follows from equation (2.14) that

$$\begin{aligned} \mathbf{F}_{w0}^* &= \frac{1}{\chi} [\text{var}(\mathbf{R}_{F0})]^{-1} E(\mathbf{R}_{F0}) - [\text{var}(\mathbf{R}_{F0})]^{-1} \text{cov}(\mathbf{R}_{c0}, \mathbf{R}_{F0}) \mathbf{C}_0 \\ &\quad - [\text{var}(\mathbf{R}_{F0})]^{-1} [\text{cov}(\mathbf{R}_{F0}, \mathbf{R}_{c1}) E(\tilde{\mathbf{C}}_1^*) + \text{cov}(\mathbf{R}_{F0}, \mathbf{R}_{F1}) E(\tilde{\mathbf{F}}_1^*)] , \end{aligned} \quad (2.17)$$

where  $\mathbf{F}_{w0}^*$  = the value of  $\mathbf{F}_0^*$  in the absence of interest rate futures markets and reinvestment opportunities.

The first two terms in equation (2.17) are of the same substance as equation (2.6). What distinguishes  $\mathbf{F}_0^*$  from  $\mathbf{F}_1^*$  is the last term which captures the bank's ability to adjust the hedge of the exchange rate risk as uncertainty is resolved at time 1. The existence of covariances in the last term implies that the second period exchange rate risks are anticipated to the extent they co-vary with randomness in the first period and effectively reflected in time 0 hedging decisions.

If we further assume that  $\tilde{\mathbf{S}}_1 = \tilde{\mathbf{Q}}_1^f$  and  $\tilde{\mathbf{S}}_2 = \tilde{\mathbf{Q}}_2^f$  so that IRP relationship can be applied to both periods, then equation (2.17) reduces to

$$\begin{aligned} \mathbf{F}_{x0}^* &= \frac{1}{\chi} [\text{var}(\tilde{\mathbf{Q}}_1^f - \mathbf{Q}_0^f)]^{-1} E(\tilde{\mathbf{Q}}_1^f - \mathbf{Q}_0^f) \\ &\quad - [\text{var}(\tilde{\mathbf{Q}}_1^f - \mathbf{Q}_0^f)]^{-1} \text{cov}[(\tilde{\mathbf{Q}}_2^f - \tilde{\mathbf{Q}}_1^f), (\tilde{\mathbf{Q}}_1^f - \mathbf{Q}_0^f)] E(\tilde{\mathbf{F}}_{x1}^*) , \end{aligned} \quad (2.18)$$

where

$\mathbf{F}_{x0}^*$  = the value of  $\mathbf{F}_0^*$  in the presence of IRP relationship and in the absence of interest rate futures markets and reinvestment opportunities.

$\mathbf{F}_{x1}^*$  = the value of  $\mathbf{F}_1^*$  in the presence of IRP relationship.

Equation (2.18) characterizes the bank's speculative demand for currency futures contracts in both periods. The first term captures the first period's speculative opportunities, while the second term reflects any autocorrelation between intertemporal currency futures returns which reflect the linkage between both period's speculative opportunities. That is, within a multi-period framework, the speculative demand for futures contracts consists of two components: conventional speculative demand and intertemporal autocorrelation of futures returns. We therefore suggest that the conventional definition of speculative demand should be modified. Equation (2.18) also provides policy implications for regulators. What worries regulators is that banks will use futures for speculative opportunities rather than for a hedging vehicle. Koppenhaver (1984) raises the question of whether or not regulatory control of futures use by banks is possible and concludes that it is possible by a fine-tuning policy that allows for legitimate hedging activity. We suggest that regulatory control can be possible only by *continued monitoring* of banks' futures positions. One time fine-tuning policy is not effective because the existence of intertemporal autocorrelation of futures returns gives banks the opportunity to circumvent that policy.

## Chapter 4

# COMPARATIVE STATIC ANALYSIS

In this section, we investigate the effect of introducing foreign exchange operations (including foreign currency positions in both spot and futures contracts) on the bank's optimal domestic loan extensions and domestic interest rate futures position.

To that end, we deliberately focus attention on time 0 hedging decisions. In addition, to make the analysis simpler (but without loss of generality), we assume the existence of a single foreign currency, a zero liability position in foreign currencies, and the availability of reinvestment opportunities at a (nonstochastic) risk free rate. Suppose that the bank is currently engaged only in domestic banking activity and holds no spot/futures positions in foreign currencies (i.e.,  $C_0 = \tilde{C}_1 = F_0 = \tilde{F}_1 = 0$ ). In this situation, the profit function reduces to

$$\tilde{\Pi}_{wo} = K_0 \tilde{\tau} + L \tilde{R}_l + f \tilde{R}_f \quad (3.1)$$

Once the bank also engages in foreign exchange operations including currency futures contracts and foreign currency denominated assets, the profit function becomes

$$\begin{aligned} \tilde{\Pi}_{wt} = & K_0 \tilde{\tau} + L \tilde{R}_l + f \tilde{R}_f + C_0 \tilde{R}_{c0} + F_0 \tilde{R}_{F0} \\ & + E(\tilde{C}_1^*) \tilde{R}_{c1} + E(\tilde{F}_1^*) \tilde{R}_{F1} \end{aligned} \quad (3.2)$$

#### 4.1 Effect of Introducing Spot Foreign Exchange Operations on Loan Extensions

The effect of introducing foreign exchange operations on the time 0 optimal decision with regard to domestic loans is determined by examining the first order conditions of equation (3.2) including international banking but evaluated at  $C_0 = \tilde{C}_1 = F_0 = \tilde{F}_1 = 0$ . Let  $C_0 = \tilde{C}_1 = F_0 = \tilde{F}_1 = 0$  be denoted by  $\Omega = 0$ . The first order condition of equation (3.2) with respect to  $L$  is given by

$$E[U'(\tilde{\Pi}_{wt}) \tilde{R}_l] = 0 \quad (3.3)$$

We define  $L_{wt}^*$  as the optimum level of loan extensions in the presence of foreign exchange operations. From equation (3.3), implicit differentiation of  $L_{wt}^*$  with respect to  $C_0$  evaluated at  $\Omega = 0$  gives

$$\left. \frac{\partial L_{wt}^*}{\partial C_0} \right|_{\Omega=0} = - \frac{E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}]}{E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l^2]} \quad (3.4)$$

The sign of equation (3.4) provides the direction of change in the bank's optimal decision on loan extensions with respect to holding positions in foreign currencies. A positive (negative) sign implies that the bank extends more (less) loans if it has access to foreign currency asset markets. From the second order condition, the denominator is negative and the sign of equation (3.4) is determined solely by the numerator,  $E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}]$ . This numerator can be expanded using the definition of covariance as

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] = E[U''(\tilde{\Pi}_{wo})] E(\tilde{R}_l \tilde{R}_{c0}) + cov[U''(\tilde{\Pi}_{wo}), \tilde{R}_l \tilde{R}_{c0}] \quad (3.5)$$

We assume that the utility function is a three-times differentiable function with  $U'''(\tilde{\Pi}_{wo}) > 0$ ,  $\tilde{\Pi}_{wo}$ ,  $\tilde{R}_l$ , and  $\tilde{R}_{c0}$  all have normal marginal distributions, and the joint distribution of  $\tilde{\Pi}_{wo}$  and  $\tilde{R}_l \tilde{R}_{c0}$  can be closely approximated by a joint normal distribution. Then, equation (3.5) can be rewritten using Rubinstein's result (1976) as

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] = E[U''(\tilde{\Pi}_{wo})] E(\tilde{R}_l \tilde{R}_{c0}) + E[U'''(\tilde{\Pi}_{wo})] cov(\tilde{\Pi}_{wo}, \tilde{R}_l \tilde{R}_{c0}) \quad (3.5a)$$

We know that if utility function is characterized by constant absolute risk aversion, then<sup>5</sup>

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<sup>5</sup> We defined in previous chapter that  $-\frac{U''(\tilde{\Pi})}{U'(\tilde{\Pi})} = \chi$ , which is a constant absolute risk aversion

parameter. Totally differentiating gives

$$-\frac{U'(\tilde{\Pi}) U'''(\tilde{\Pi}) - [U''(\tilde{\Pi})]^2}{[U'(\tilde{\Pi})]^2} = 0.$$

This implies that

$$\frac{U''(\tilde{\Pi})}{U'(\tilde{\Pi})} = \frac{U'''(\tilde{\Pi})}{U''(\tilde{\Pi})} = -\chi.$$

$$- \frac{E[U''''(\tilde{\Pi}_{wo})]}{E[U''(\tilde{\Pi}_{wo})]} = \chi.$$

Also, it is shown by Stevens (1971) that if  $\tilde{x}$ ,  $\tilde{y}$ , and  $\tilde{z}$  all have normal marginal distributions, then

$$cov(\tilde{x}\tilde{y}, \tilde{z}) = E(\tilde{y}) cov(\tilde{x}, \tilde{z}) + E(\tilde{x}) cov(\tilde{y}, \tilde{z})$$

Using the above characteristics of constant absolute risk aversion and Stevens' result, we can rewrite equation (3.5a) as

$$\begin{aligned} E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] &= E[U''(\tilde{\Pi}_{wo})] \{ [cov(\tilde{R}_l \tilde{R}_{c0}) + E(\tilde{R}_l) E(\tilde{R}_{c0})] \\ &\quad - \chi [E(\tilde{R}_{c0}) cov(\tilde{\Pi}_{wo}, \tilde{R}_l) + E(\tilde{R}_l) cov(\tilde{\Pi}_{wo}, \tilde{R}_{c0})] \} \end{aligned} \quad (3.5b)$$

Equation (3.5b) can be simplified by using the first order condition with respect to  $L$  in the absence of foreign exchange operations. The first order condition under the assumption of a utility function which is characterized by constant absolute risk aversion is given by

$$E(\tilde{R}_l) = \chi cov(\tilde{\Pi}_{wo}, \tilde{R}_l) \quad (3.6a)$$

It can be shown that

$$cov(\tilde{\Pi}_{wo}, \tilde{R}_{c0}) = L_{wo} cov(\tilde{R}_l, \tilde{R}_{c0}) + f_{wo} cov(\tilde{R}_f, \tilde{R}_{c0}) \quad (3.6b)$$

Substituting (3.6a) and (3.6b) into (3.5b) gives

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] = E[U''(\tilde{\Pi}_{wo})] \{ cov(\tilde{R}_l, \tilde{R}_{c0})$$

$$- \chi E(\tilde{R}_l) [L_{wo} cov(\tilde{R}_l, \tilde{R}_{c0}) + f_{wo} cov(\tilde{R}_f, \tilde{R}_{c0})] \} \quad (3.7)$$

Equation (3.7) provides the following proposition.

**Proposition 2.** (a) If the net interest revenue (net of deposit costs) per unit of loans is expected to be zero, then the existence and availability of foreign currency spot markets induces the risk-averse bank to extend more (less) loans as CD (or Eurodollar) interest rates are positively (negatively) correlated with foreign exchange rates.

(b) If the bank perceives *ex ante* positive net interest revenue and domestic CD (or Eurodollar) interest rates are independent of foreign exchange rates, then the existence and availability of foreign currency spot markets induces the risk-averse bank to extend more (less) loans as spot foreign exchange rates are negatively (positively) correlated with interest futures rates.<sup>6</sup>

*proof.* (a) Under the assumption that  $E(\tilde{R}) = 0$ , equation (3.7) reduces to

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] = E[U''(\tilde{\Pi}_{wo})] cov(\tilde{R}_l, \tilde{R}_{c0}).$$

However,

$$cov(\tilde{R}_l, \tilde{R}_{c0}) = cov[(R_L - \tilde{R}_l), (1 + R_{free})(1 + R_0^*) \tilde{S}_1]$$

or

$$cov(\tilde{R}_l, \tilde{R}_{c0}) = - (1 + R_{free})(1 + R_0^*) cov(\tilde{R}_l, \tilde{S}_1),$$

---

<sup>6</sup> We presuppose that  $f_{wo} < 0$  for this proposition. Kopenhagen (1990) reports that banks with assets greater than \$500 million have been net short in futures and forward contracts during 1983-1987. However, if  $f_{wo} > 0$ , the reverse of the proposition holds true.

where  $R_{free}$  = the (nonstochastic) risk-free reinvestment rate prevailing in the second period. Since  $E[U''(\tilde{\Pi}_{wo})] < 0$  by the strict concavity of utility function, we obtain

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] \begin{matrix} \geq \\ < \end{matrix} 0 \quad \text{as } cov(\tilde{R}_1, \tilde{S}_1) \begin{matrix} \geq \\ < \end{matrix} 0 .$$

(b) If  $cov(\tilde{R}_l, \tilde{R}_{c0}) = 0$ , then equation (3.7) reduces to

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] = -\chi f_{wo} E[U''(\tilde{\Pi}_{wo})] E(\tilde{R}_l) cov(\tilde{R}_f, \tilde{R}_{c0}) .$$

However,

$$cov(\tilde{R}_f, \tilde{R}_{c0}) = (1 + R_{free})^2 (1 + R_0^*) cov(\tilde{S}_1, \tilde{P}_1^f) .$$

If  $E(\tilde{R}_l) > 0$ , we obtain

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_l \tilde{R}_{c0}] \begin{matrix} \geq \\ < \end{matrix} 0 \quad \text{as } cov(\tilde{S}_1, \tilde{P}_1^f) \begin{matrix} \leq \\ > \end{matrix} 0 .$$

An intuitive explanation for the proposition can be made within the context of return-risk tradeoff. Given that net interest revenue per unit of loans is expected to be zero, positive (negative) correlation between CD (or Eurodollar) interest costs and exchange rates decreases (increases) the covariance risk between net interest revenue and return from holding foreign currencies. The reduction (rise) in the covariance risk, in turn, reduces (raises) the variability of bank profits. Thus, the risk-averse bank optimally extends more (less) loans when CD (or Eurodollar) interest rates are positively (negatively) correlated with foreign exchange rates. On the other hand, positive (negative) correlation between spot foreign exchange rates and interest futures rates increases (decreases) the covariance risk between returns on holding foreign currencies and from trading interest futures contracts. The rise (reduction) in the covariance risk raises

(reduces) the variability of profits. The rise (reduction) in the variability of profits arising from the existence and availability of spot currency markets dominates (is dominated by) *ex ante* positive profit opportunities (from assumption) in the loan market. The bank, therefore, optimally extends less (more) loans.

*Comment:* Changes in domestic interest rates relative to foreign interest rates are often cited in international monetary economics as a major factor affecting exchange rates. Suppose that the domestic CD (or Eurodollar) interest rate rises while expected inflation is exogenously given. Then, the rise in domestic CD (or Eurodollar) interest rates indicates that the expected return on dollar assets relative to foreign assets will increase at all exchange rates. The demand for dollar assets will increase and the value of the dollar appreciates (or the foreign currency depreciates). That is,  $\tilde{S}_1$  decreases in our model. This suggests that  $cov(\tilde{R}_1, \tilde{S}_1) < 0$  and thus the existence and availability of foreign currency spot markets induces the risk-averse bank to extend less loans, given expected inflation and zero expected net interest revenue.<sup>7</sup>

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<sup>7</sup> However, when the domestic CD (or Eurodollar) interest rate rises because of an increase in expected inflation, we will get a different result. The rise in domestic expected inflation leads to an expected depreciation of the dollar which is typically thought to be larger than the increase in the domestic CD (or Eurodollar) interest rate. As a result, the expected return on dollar assets falls relative to the expected return on foreign assets. The demand for dollar assets declines and the value of dollar depreciates. This suggests that  $cov(\tilde{R}_1, \tilde{S}_1) > 0$  and thus the bank will extend more loans.

## 4.2 Effect of Introducing Currency Futures Markets on Interest Rate

### Futures Position

In this part, we seek to examine the effect of introducing currency futures markets on the bank's optimal interest rate futures position. Our desire is to demonstrate that extant bank hedging literature that does not consider the interdependence between interest and exchange rates is misleading about the optimal futures position. In fact, the bank's willingness to establish interest rate futures contracts to hedge interest rate risks will be influenced by the existence and availability of currency futures markets. Due to the interdependence between interest and exchange rates (and thus interdependence between interest futures and currency futures rates), part of the interest rate risk could be covered by positioning in currency futures contracts.

By exactly parallel reasoning that we have followed in the previous section, we examine the implicit function of the first order condition. The first order condition of equation (3.2) with respect to  $f$  is given by

$$E [U' (\tilde{\Pi}_{wi}) \tilde{R}_f] = 0 \quad (3.8)$$

The optimal interest rate futures position in the presence of currency futures markets is obtained from the solution of equation (3.8). Implicit differentiation of  $f_{wi}^*$  with respect to  $F_0$  evaluated at  $\Omega = 0$  gives

$$\left. \frac{\partial f_{wi}^*}{\partial F_0} \right|_{\Omega=0} = - \frac{E [U'' (\tilde{\Pi}_{wo}) \tilde{R}_f \tilde{R}_{F0}]}{E [U'' (\tilde{\Pi}_{wo}) \tilde{R}_f^2]} \quad (3.9)$$

The numerator of equation (3.9) can be expanded by the same manner as we have pursued in section 3.1.

$$E [U''(\tilde{\Pi}_{wo}) \tilde{R}_f \tilde{R}_{F0}] = E [U''(\tilde{\Pi}_{wo})] \{ cov(\tilde{R}_f, \tilde{R}_{F0}) - \chi E(\tilde{R}_f) [L_{wo} cov(\tilde{R}_I, \tilde{R}_{F0}) + f_{wo} cov(\tilde{R}_f, \tilde{R}_{F0})] \} \quad (3.10)$$

Equation (3.10) provides the following proposition.

**Proposition 3.** (a) If the bank perceives *ex ante* profit opportunities in the interest rate futures market and interest rate futures rates are independent of currency futures rates, then the existence and availability of currency futures markets induces the risk-averse bank to establish more (less) interest rate futures position as CD (or Eurodollar) interest rates are negatively (positively) correlated with currency futures rates.

(b) If interest rate futures markets are represented by martingale-efficiency, then the existence and availability of currency futures markets induces the bank to establish more (less) interest rate futures position to hedge interest rate risks as interest futures and currency futures rates are negatively (positively) correlated.

*Proof.* (a) If  $cov(\tilde{R}_f, \tilde{R}_{F0}) = 0$ , then equation (3.10) reduces to

$$E [U''(\tilde{\Pi}_{wo}) \tilde{R}_f \tilde{R}_{F0}] = - \chi L_{wo} E [U''(\tilde{\Pi}_{wo})] E(\tilde{R}_f) cov(\tilde{R}_I, \tilde{R}_{F0}) .$$

However,

$$cov(\tilde{R}_I, \tilde{R}_{F0}) = - (1 + R_{free}) cov(\tilde{R}_I, \tilde{Q}_I) .$$

If  $E(\tilde{R}_f) > 0$ , then

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_f \tilde{R}_{F0}] \underset{\leq}{\geq} 0 \quad \text{as } cov(\tilde{R}_1, \tilde{Q}_1^f) \underset{\leq}{\geq} 0 .$$

(b) If  $E(\tilde{R}_f) = 0$ , then equation (3.10) reduces to

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_f \tilde{R}_{F0}] = E[U''(\tilde{\Pi}_{wo})] cov(\tilde{R}_f, \tilde{R}_{F0}) .$$

Since  $cov(\tilde{R}_f, \tilde{R}_{F0}) = (1 + R_{f**})^2 cov(\tilde{P}_1^f, \tilde{Q}_1^f)$  and  $E[U''(\tilde{\Pi}_{wo})] < 0$ , we can conclude that

$$E[U''(\tilde{\Pi}_{wo}) \tilde{R}_f \tilde{R}_{F0}] \underset{\leq}{\geq} 0 \quad \text{as } cov(\tilde{P}_1^f, \tilde{Q}_1^f) \underset{\leq}{\geq} 0 .$$

An intuitive explanation for the proposition can be made following the same line of reasoning as in proposition 2. Given the assumptions of (a), positive (negative) correlation between CD (or Eurodollar) interest costs and currency futures rates decreases (increases) the covariance risk between net interest revenue and return from trading currency futures contracts. The reduction (rise) in the covariance risk, in turn, reduces (raises) the variability of bank profits. This reduction (rise) in the variability of profits due to the existence and availability of currency futures markets dominates (is dominated by) *ex ante* positive profit opportunities (from assumption) in the interest rate futures market. The risk-averse bank, therefore, optimally establishes less (more) interest rate futures position when CD (or Eurodollar) interest rates are positively (negatively) correlated with currency futures rates. On the other hand, given the martingale-efficient interest rate futures markets of (b), positive (negative) correlation between interest futures and currency futures rates raises (reduces) the variability of bank profits. Hence, the existence and availability of currency futures markets induces the risk-averse bank to establish less (more) interest rate futures position when interest futures and currency futures rates are positively (negatively) correlated.

# Chapter 5

## EMPIRICAL ANALYSIS

In this chapter, we design empirical tests based on the theoretical analysis, as described in the previous chapters. We seek to estimate joint optimal hedge ratios and implement hypothesis tests.

### 5.1 Econometric Issues

The joint optimal hedge ratios for the bank facing both exchange and interest rate risks can be empirically estimated by recognizing the structure of *multivariate* regressions. To begin with, we estimate the time 0 optimal joint hedge ratios, assuming that the bank's participation in futures markets is not motivated by the speculative opportunities, i.e., the minimum risk hedge ratio. Then, equation (2.15) can be stacked into a system as

$$\mathbf{g}_h^* = \mathbf{A}K_0 + \mathbf{B}\Gamma \quad (4.1)$$

, where

$$\mathbf{A} = -\Sigma_{11}^{-1} \begin{bmatrix} \text{cov}(\tilde{R}_f, \tilde{\tau}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\tau}) \end{bmatrix}, \quad \mathbf{B} = -\Sigma_{11}^{-1} \Sigma_*, \quad \Gamma = \begin{bmatrix} \mathbf{y} \\ \mathbf{E}(\tilde{\mathbf{p}}_2^*) \end{bmatrix},$$

$$\Sigma_{11} = \begin{bmatrix} \text{var}(\tilde{R}_f) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F0}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_f) & \text{var}(\tilde{\mathbf{R}}_{F0}) \end{bmatrix},$$

$$\Sigma_* = \begin{bmatrix} \text{cov}(\tilde{R}_f, \tilde{R}_l) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c0}) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F1}) \\ \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_l) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c0}) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c1}) & \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{F1}) \end{bmatrix}.$$

$\mathbf{A}$  is  $(n + 1) \times 1$  column vector of constants and reflects the role of capital adequacy arising from the existence of reinvestment opportunities. That is, the extent to which the regulatory capital requirement influences the bank's optimal futures position is given by the coefficients of the theoretical multiple regressions of  $\tilde{\tau}$  on  $(\tilde{R}_f, \tilde{\mathbf{R}}_{F0})$ .  $\mathbf{B}$  is  $(n + 1) \times (3n + 1)$  matrix of hedge ratios and  $\Gamma$  is  $(3n + 1) \times 1$  column vector of underlying asset positions to be jointly hedged. Equation (4.1) suggests that the bank should hedge an "anticipatory position risk" as well as exchange rate and interest rate risks. The decisions on  $L$ ,  $\mathbf{C}_0$ , and  $\mathbf{E}(\tilde{\mathbf{p}}_2^*)$  establish interest rate risk, exchange risk, and anticipatory position risk, respectively. The anticipatory position risk occurs when there exist futures and spot market positions expected to be taken in the future [See, Koppenhaver (1984)]. The bank's time 0 optimal joint hedge ratio such that exchange rate risk, interest rate risk, and anticipatory position risk are minimized simultaneously is given by  $\mathbf{B}$  ( $= [\Sigma_{11}^{-1} \Sigma_*]$ ) which is the  $(n + 1) \times (3n + 1)$  matrix of the coefficients of the theoretical *multivariate* regressions of  $(\tilde{R}_l, \tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{c1}, \tilde{\mathbf{R}}_{F1})$  on  $(\tilde{R}_f, \tilde{\mathbf{R}}_{F0})$ .

The empirical tests associated with an estimation of *multivariate* regression coefficients require careful examination of their statistical validity. Due to an integrated framework of interest and currency futures markets in our model, we need a technique that allows for a simultaneous estimation of different futures returns and thus a system-wide application [See, Hodrick and Srivastava (1987), Morgan, Shome, and Smith (1988), Meese and Rogoff (1989), Huang (1990), for various examples of system estimation]. Also, returns in foreign currency spot and futures markets show substantial time-varying variance that can be represented as conditional heteroskedasticity [See, Cumby and Obstfeld (1983), Hansen and Hodrick (1980, 1983), Hsieh (1988), Giovannini and Jorion (1989), Lewis (1990)]. These characteristics in international financial assets give rise to a difficulty in extracting reliable statistical estimates by means of conventional econometric techniques. In addition, the presence of conditional heteroskedasticity creates uncertainty about the interpretation of the test statistics [See, Hodrick (1987)].

Recently, Engle (1982), Hansen (1982), and Bollerslev (1986), among others, have developed econometric techniques that allow us to tackle the conditional heteroskedasticity problem. ARCH (Autoregressive Conditional Heteroskedasticity) model suggested by Engle (1982), imposes an autoregressive structure on conditional variance of a time series, allowing disturbances to change stochastically over the sample period. The conditional variance is modelled as a linear function of past squared errors, leaving the unconditional variance constant. ARCH processes are mean zero, serially uncorrelated (but not independent as the disturbances are related through second moments) processes with nonconstant variances conditional on the past (but constant unconditional) variances. Bollerslev (1986) has extended ARCH model, allowing lagged

conditional variances to enter as well in the construction of conditional variances [GARCH (Generalized ARCH)].

An alternative statistical technique is GMM (Generalized Method of Moments) model suggested by Hansen (1982). Assuming stationarity and ergodicity of observable variables, the GMM model constructs population orthogonality conditions on the disturbance terms allowing for both serial correlation and conditional heteroskedasticity. A GMM estimator is obtained by minimizing the criterion function which is a quadratic form of the orthogonality conditions with appropriate weighting matrix.

While the two types of econometric models (GMM and GARCH) that tackle the conditional heteroskedasticity problem achieve the same *consistency* of estimators, GMM which is an analogue to SUR (Seemingly Unrelated Regression) provides a way to estimate the parameters of system and is more appropriate for meeting our needs. GMM is applicable regardless of the frequency of the data, while GARCH is applicable only to daily or weekly data [See, Hodrick (1987) and Hsieh (1989)]. GMM produces a robust estimation [See, Mark (1988)].

## 5.2 Estimation Issues

As mentioned in the footnote of Chapter 2, the use of currency futures contracts by U.S. banks is concentrated among the German mark, British pound, Japanese yen, Swiss franc, and Canadian dollar. Conforming to our theoretical analysis, we assume that U.S. banks use only T/B futures contracts to hedge interest rate risks. This produces a total of six different futures contracts differentiated by contract type and foreign cur-

rency to be analyzed. Following Hansen (1982), Hodrick and Srivastava (1987), and Meese and Rogoff (1988), we describe the GMM estimation procedure.

Before proceeding, we define

$T$  = the number of observations.

$Y' = [\tau R_{i,t} R_{C0,t} R_{C1,t} R_{F1,t}]$ , where  $j = 1, 2, \dots, 5$ .

$X_k$  = the  $(T \times 7)$  matrix with typical row element of  $(1, R_{f,t}, R_{F0,t})$ , where  $k = 1, 2, 3, \dots, 17$ .

$\beta_k$  = the  $(7 \times 1)$  vector of regression coefficients.

$\epsilon_k$  = the  $(T \times 1)$  vector of disturbances.

Then, the system of equations can be written as

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ Y_{17} \end{bmatrix} = \begin{bmatrix} X_1 & 0 & 0 & & & & 0 \\ 0 & X_2 & 0 & & & & 0 \\ 0 & 0 & X_3 & \cdot & \cdot & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & 0 & & & & X_{17} \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \beta_{17} \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \epsilon_3 \\ \cdot \\ \cdot \\ \cdot \\ \cdot \\ \epsilon_{17} \end{bmatrix}$$

This can be written more compactly as

$$Y = X\beta + \varepsilon, \quad (4.2)$$

The dimension of  $Y$  is a  $(17T \times 1)$  vector,  $X$  is a  $(17T \times 119)$  matrix,  $\beta$  is a  $(119 \times 1)$  vector and  $\varepsilon$  is a  $(17T \times 1)$  vector.

Following Hodrick and Srivastava (1987), we can write the matrix of instruments as

$$Z = I \otimes \begin{bmatrix} Z'_1 \\ Z'_2 \\ \cdot \\ \cdot \\ \cdot \\ Z'_T \end{bmatrix}$$

, where

$I$  = the identity matrix of dimension seventeen.

$Z'_t = [1 \ Z_{1,t} \ Z_{2,t} \ \dots \ Z_{6,t}]$ , where  $Z_{j,t}$  is the observation on the  $j$ th futures instrument at time  $t$ .

$\otimes$  = the Kronecker product.

$Z$  = the  $(17T \times 119)$  matrix of instruments.

We choose Eurodollar rates as instrument for  $\tilde{R}_1$ , Eurodollar futures rate differentials as instrument for  $(\tilde{P}_f - P_f)$ , and forward exchange rate differentials as instrument for  $(\tilde{Q}_f - Q_f)$ . This is because the instrumental variables chosen are shown to be highly correlated with exogenous variables [See, Tables 1 and 2]. It follows that the sample orthogonality conditions are given by

$$\mathbf{g}_T(\boldsymbol{\beta}) = \frac{\mathbf{Z}'\boldsymbol{\varepsilon}}{T} \quad (4.3)$$

, where  $\boldsymbol{\varepsilon} = \mathbf{Y} - \mathbf{X}\boldsymbol{\beta}$ . The GMM criterion (distance) function is obtained by making  $\mathbf{g}_T(\boldsymbol{\beta})$  a quadratic form with appropriate weighting matrix [See, Hansen (1982)] and is given by

$$\mathbf{J}_T(\boldsymbol{\beta}) = \left(\frac{1}{T}\right)^2 \boldsymbol{\varepsilon}'\mathbf{Z}\mathbf{W}_T\mathbf{Z}'\boldsymbol{\varepsilon} \quad (4.4)$$

, where  $\mathbf{W}_T$  = the  $(119 \times 119)$  symmetric weighting matrix. The GMM estimates for  $\boldsymbol{\beta}$  are chosen by minimizing the criterion (distance) function, (4.4), with respect to  $\boldsymbol{\beta}$ .

$$\hat{\boldsymbol{\beta}}_{GMM} = (\mathbf{X}'\mathbf{Z}\hat{\mathbf{W}}_T\mathbf{Z}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{Z}\hat{\mathbf{W}}_T\mathbf{Z}'\mathbf{Y} \quad (4.5)$$

Hansen (1982) shows that  $\hat{\boldsymbol{\beta}}_{GMM}$  is consistent and asymptotically normal. Newey and West (1987) demonstrate that the optimal choice of  $\hat{\mathbf{W}}_T$  as a positive-definite time-domain estimator is

$$\hat{\mathbf{W}}_T = \left[ \hat{\Phi}_0 + \sum_{j=1}^{m=17} \phi(j,m) (\hat{\Phi}_j + \hat{\Phi}'_j) \right]^{-1} \quad (4.6)$$

, where

$$\phi(j,m) = 1 - \frac{j}{m+1}$$

$$\hat{\Phi}_j = \left(\frac{1}{T}\right) \sum_{t=j+1}^T \hat{\mathbf{h}}_t \hat{\mathbf{h}}_{t-j}'$$

, where  $\hat{\mathbf{h}}_t$  has as its typical element  $Z_{jt} \hat{\varepsilon}_t$ .

## 5.3 Data and Methodology

Equation (4.1) is the starting point for the empirical test. We estimate **A** and **B** using a GMM model, given various return data on spot and futures contracts. The matrix of parameter estimates derived from the GMM estimation will be used to implement the hypothesis tests.

### 5.3.1 Descriptive Statistics

For an illustration of volatilities of and correlations among (spot and futures) interest and foreign exchange rates, we present Figures 1 through 8 and Tables 1 through 2.

Figure 1 exhibits that Eurodollar interest rates have been higher than domestic CD rates throughout our sample period but the magnitude of the difference has been reduced to a great extent in the late 1980's. The two interest rates have moved in the same direction, reflecting positive correlation. Figure 2 shows that foreign exchange rates in the second half of the 1980's have been higher than those in the first half of the 1980's, indicating a depreciation of the U.S. dollar. Figures 3 and 4 show the same evolution of the futures rates as that of the spot rates. The variability of interest rates as measured by absolute deviation from mean and of foreign exchange rates as measured by percentage absolute deviation from mean is presented in Figures 5 and 6, showing a great deal of volatility in interest and foreign exchange rates. Interest and currency futures rates have also been greatly volatile as seen in Figures 7 and 8. Table 1 demonstrates highly (but not perfectly) negative correlations among domestic CD rates and foreign exchange rates (with the exception of British pound), which is consistent with the

partial equilibrium version of IRP theorem. Foreign exchange rates are highly positively correlated to one another.

In summary, during our sample period, interest and foreign exchange rates have been extremely volatile and highly (but not perfectly) negatively correlated. This empirical evidence provides substantiation for us to focus attention on bank risk management, particularly in a simultaneous framework.

### ***5.3.2 The Estimation of Optimal Hedge Ratios***

To estimate **A** and **B** using a GMM model, we construct all the returns associated with bank hedging activities (i.e.,  $\tilde{\tau}$ ,  $\tilde{R}_t$ ,  $\tilde{R}_f$ ,  $\tilde{R}_{c0}$ ,  $\tilde{R}_{c1}$ ,  $\tilde{R}_{F0}$ ,  $\tilde{R}_{F1}$ ) for a given holding period. These returns are constructed consistent with a two-period model. This two-period perspective dictates the construction of the data set for this study. The spot and futures rates are collected for foreign currencies: the British pound, Canadian dollar, Japanese yen, Swiss franc, and German mark, all relative to the U.S. dollar. The data are closing quotations of the third Monday of March, June, September, and December from the *Wall Street Journal*. Not a single Monday falls on a holiday in our sample periods. Prime rates charged by banks are used as a proxy for loan rates and are obtained from the *Federal Reserve Bulletin*. Foreign interest rates and CD rates are also obtained from the *Federal Reserve Bulletin*. Based on these raw data (time-series), we construct a data set of relevant *ex post* returns.

International Monetary Market (IMM) currency futures contracts are delivered on the third Wednesday of March, June, September, and December and expire two business days earlier on the delivery date. There is also a two-day delivery lag for spot contracts.

To match the spot settlement date to the delivery date on the currency futures contract requires that the maturity for the currency futures rate correspond to the spot exchange rate at the expiration. The T-bill futures contract has a time to maturity of 90 days at the expiration of the futures contract. The contracts trade for delivery in March, June, September, and December with trading ending according to a schedule established by the Chicago Mercantile Exchange. Like the T-bill futures contract,<sup>8</sup> the Eurodollar futures contract has a three-month maturity but trading ends on the same day as the currency futures contract. To avoid a conflict in expiration dates between the foreign currency futures contract and the T-bill futures contract, we assume that banks liquidate T-bill futures positions on the day when foreign currency futures contracts expire. We also assume that long-term loans have six-month maturity and the bank receives two interest payments.

To minimize the potential for mismatching in spot-futures return comparisons, we adopt a quarterly sampling interval of the data, beginning in June 1982 and ending in March 1990. We can construct 30 six-month grand periods for the entire time horizon, each of which is divided into two equal length holding-periods to comply with the theoretical part of the study. The first grand period begins in June 1982 and ends in December 1982. Each subsequent grand period is constructed by adding new quarterly spot and futures return data and deleting the initial quarter's data for a period of December 1982 thru March 1990. Using this moving window procedure, we can construct 60 quarterly holding-period returns. The autocorrelation caused by this moving window procedure does not harm the estimation because GMM accounts for any autocorrelation as well as cross equation correlations.

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<sup>8</sup> But unlike the T-bill contract, the Eurodollar futures contract is fulfilled by cash settlement.

The optimal hedge ratios can be estimated by running the following 17 regression equations as a GMM model:

$$\tau = \beta_{1,1} + \beta_{1,2}R_{f,t} + \beta_{1,3}R_{F0,t}^1 + \beta_{1,4}R_{F0,t}^2 + \dots + \beta_{1,7}R_{F0,t}^5 + \varepsilon_{1,t},$$

$$R_{i,t} = \beta_{2,1} + \beta_{2,2}R_{f,t} + \beta_{2,3}R_{F0,t}^1 + \beta_{2,4}R_{F0,t}^2 + \dots + \beta_{2,7}R_{F0,t}^5 + \varepsilon_{2,t}$$

$$R_{C0,t}^1 = \beta_{3,1} + \beta_{3,2}R_{f,t} + \beta_{3,3}R_{F0,t}^1 + \beta_{3,4}R_{F0,t}^2 + \dots + \beta_{3,7}R_{F0,t}^5 + \varepsilon_{3,t}$$

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$$R_{C0,t}^5 = \beta_{7,1} + \beta_{7,2}R_{f,t} + \beta_{7,3}R_{F0,t}^1 + \beta_{7,4}R_{F0,t}^2 + \dots + \beta_{7,7}R_{F0,t}^5 + \varepsilon_{7,t}$$

$$R_{C1,t}^1 = \beta_{8,1} + \beta_{8,2}R_{f,t} + \beta_{8,3}R_{F0,t}^1 + \beta_{8,4}R_{F0,t}^2 + \dots + \beta_{8,7}R_{F0,t}^5 + \varepsilon_{8,t}$$

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$$R_{C1,t}^5 = \beta_{12,1} + \beta_{12,2}R_{f,t} + \beta_{12,3}R_{F0,t}^1 + \beta_{12,4}R_{F0,t}^2 + \dots + \beta_{12,7}R_{F0,t}^5 + \varepsilon_{12,t}$$

$$R_{F1,t}^1 = \beta_{13,1} + \beta_{13,2}R_{f,t} + \beta_{13,3}R_{F0,t}^1 + \beta_{13,4}R_{F0,t}^2 + \dots + \beta_{13,7}R_{F0,t}^5 + \varepsilon_{13,t}$$

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$$R_{F1,t}^5 = \beta_{17,1} + \beta_{17,2}R_{f,t} + \beta_{17,3}R_{F0,t}^1 + \beta_{17,4}R_{F0,t}^2 + \dots + \beta_{17,7}R_{F0,t}^5 + \varepsilon_{17,t}$$

### 5.3.3 Hypothesis Tests

The following five hypotheses can be tested from the GMM estimation.

#### (1) Capital Adequacy Irrelevance Hypothesis

$$H_0: \text{all } \beta_{1j} = 0 \text{ for } j = 2, 3, \dots, 7.$$

The implication would be that the terminal level of capital (after accounting for reinvestment opportunities) should not be taken into consideration by banks in formulating optimal futures positions.<sup>9</sup> We will refer to this as the "capital adequacy irrelevance hypothesis". Based on theory, we expect to reject this hypothesis because the level of capital contributes to a decrease in interest rate risk and therefore should reduce the number of futures contracts banks should take. Capital does not play a role in foreign exchange risk and we expect irrelevance with respect to foreign currency futures positions.

#### (2) Naive-Single Market Hypothesis

$$H_0: \begin{cases} \text{all } \beta_{ij} = 0 \text{ if } i \neq j \\ \text{and} \\ \text{all } \beta_{ij} = 1 \text{ if } i = j \end{cases}$$

for each  $i$  ( $i = 2, 3, \dots, 7$  and  $j = 2, 3, \dots, 7$ ).

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<sup>9</sup> The importance of this problem has been addressed by Morgan and Smith (1987). However, this problem has received no attention in the empirical hedging literature.

The hypothesis is that to hedge the  $i$ th type of spot position, the bank should take only a position in the corresponding ( $i = j$ ) futures contract that is opposite in sign but in the same amount of units as the  $i$ th type of instrument being hedged in the presence of both interest and foreign exchange rate risks. This hypothesis is a joint hypothesis on the magnitude of the position and that cross-hedging is unnecessary. We will refer to this as the "naive-single market hypothesis". We anticipate that this hypothesis will be rejected based on the belief that correlations are high (but not perfect) between foreign exchange rates and interest rates.

### (3) Own-Market Hypothesis

$$H_0 : \text{all } \beta_{i,j} = 0$$

for each  $i$  ( $i = 2,3,\dots,7$  and  $j = 2,3,\dots,7$ ) and  $i \neq j$ .

This implies that to hedge the  $i$ th type of spot position, the bank will take a position only in the corresponding ( $i = j$ ) futures contract (but not naively) and will not take into consideration any cross-hedging opportunities. The value of  $\beta_{i,j}$  being significantly different from zero implies that the bank will engage in cross-hedging activities to hedge a specific type of spot position. This is a subset of the naive-single market hypothesis. Again we expect to reject this hypothesis.

### (4) Intertemporal Position Irrelevance Hypothesis

$$H_0 : \text{all } \beta_{i,j} = 0$$

for each  $i$  ( $i = 8,9,\dots,17$  and  $j = 2,3,\dots,7$ ).

This implies that current positions (whether they are spot or futures) should not account for future positions (spot or futures) that banks will take for the next period, i.e., future positions are irrelevant when they make current decisions on the spot and futures positions. We will refer to this as the "intertemporal position irrelevance hypothesis". This test is designed to identify any intertemporal component to hedging behavior that would result from correlations in price movements across periods.

#### (5) International Banking Hypothesis

We desire to implement a test of whether or not hedge ratios are the same for domestic and international banks. This test is given by the null hypothesis that

$$\mathbf{H}_0: \sum_{i=3}^7 \beta_{ij} = 0$$

for each  $j = 1, 2, \dots, 7$ .

This implies that optimal hedge ratios are the same for the two types of banks. We will refer to this as the "international banking hypothesis".

Alternatively, this null hypothesis test can be implemented by demonstrating that the parameters of each of the following two time-series regression equations are the same:

$$R_t^{dom} = \beta_1 + \beta_2 R_{f,t} + \beta_3 R_{FOB,t} + \dots + \beta_7 R_{FOG,t} + \varepsilon_t$$

and

$$R_t^{in} = \gamma_1 + \gamma_2 R_{f,t} + \gamma_3 R_{F0B,t} + \dots + \gamma_7 R_{F0G,t} + \varepsilon_t$$

,where

$R_t^{dom}$  = the sum of  $\tau$  and  $R_t$ , which reflects the spot return from engaging in domestic banking activity only.

$R_t^{in}$  = the portfolio return as measured by the sum of  $\tau$ ,  $R_t$ ,  $R_{C0B}$ ,  $R_{C0C}$ ,  $R_{C0J}$ ,  $R_{C0S}$ , and  $R_{C0G}$ , which reflects the spot return from engaging in global banking activity.

The null hypothesis then would be

$$H_0: \beta_1 = \gamma_1, \beta_2 = \gamma_2, \dots, \beta_7 = \gamma_7.$$

This implies that hedge ratios in the presence of international banking activity are the same as those in the absence of international banking activity. This enables us to use a *Chow* test which is well-known in econometrics for the equality test of two regression equations. The appropriate test statistic for the *Chow* test is given by

$$\frac{(SSE_R - SSE_1 - SSE_2) / K}{(SSE_1 + SSE_2) / (n_1 + n_2 - 2K)}$$

which is (asymptotically) distributed as an **F** with  $K$  degrees of freedom for the numerator and  $(n_1 + n_2 - 2K)$  degrees of freedom for the denominator.  $K$  represents the number of parameters to be estimated and  $n_1$  ( $n_2$ ) represents the number of observations for the first (second) regression equation as described by the above.  $SSE_R$  represents

the error sum of squares for the  $(n_1 + n_2)$  observations and  $SSE_1$  ( $SSE_2$ ) represents the error sum of squares for the first (second)  $n_1$  ( $n_2$ ) observations.

For tests other than the alternative test of international banking hypothesis, we follow Hodrick & Srivastava (1987), Meese & Rogoff (1989), and Huang (1990) in which tests are conducted by employing a *Wald* test with constraint of  $\mathbf{H}\hat{\boldsymbol{\beta}}_{GMM} = \boldsymbol{\gamma}$ . It is shown by Hansen (1982) that from the asymptotic distribution theory

$$(\mathbf{H}\hat{\boldsymbol{\beta}}_{GMM} - \boldsymbol{\gamma})' \left[ \frac{\mathbf{H} V(\hat{\boldsymbol{\beta}}_{GMM}) \mathbf{H}'}{T} \right]^{-1} (\mathbf{H}\hat{\boldsymbol{\beta}}_{GMM} - \boldsymbol{\gamma})$$

is distributed as a chi-square with degrees of freedom equal to the row dimension of  $\mathbf{H}$ .

## 5.4 Empirical Results

The results from estimating the regression equations with SUR and GMM techniques are presented in Table 3 and Table 4 respectively. The results from the *Wald* test for the hypothesis tests are presented in Table 5 through Table 9. In Tables 3 and 4, the first column lists dependent variables and each row lists the coefficients for the independent variables as required by regression equations in section 5.3.2. Panel A of Table 4 reports GMM hedge ratio estimates for hedging against the uncertainty of various spot positions. For example, the GMM hedge ratios for hedging the interest rate risks are -0.4502 for interest rate futures contracts, -0.0174 for British pound futures contracts, 0.0383 for Canadian dollar futures contracts (though not statistically significant), 0.0190 for Japanese yen futures contracts (though not statistically significant), -0.0803 for Swiss franc futures contracts (though not statistically significant), and 0.0730 for German mark futures contracts. Panel B of Table 4 reports the GMM hedge ratio estimates for hedging anticipatory foreign currency spot positions. For example, the GMM hedge ratios for hedging the anticipatory British pound spot position risk are 1.6327 for interest rate futures contracts, -0.0582 for British pound futures contracts (though not statistically significant), 1.1952 for Canadian dollar futures contracts, 2.1385 for Japanese yen futures contracts, -1.1563 for Swiss franc futures contracts (though not statistically significant), and -1.6501 for German mark futures contracts (though not statistically significant). Panel C of Table 4 reports the GMM hedge ratio estimates for hedging anticipatory currency futures position risks.

Table 5 through Table 9 report the values of the chi-square test statistics for various hypotheses. For example, the second row of Table 7 shows that the value of the chi-square test statistic of 168.1732 which is large in number provides evidence against

the null hypothesis that taking only interest rate futures positions with an appropriate hedge ratio is complete enough to hedge interest rate risks. Table 9 shows the value of the F-test statistic from employing *Chow* test for international banking hypothesis.

#### ***5.4.1 Point Estimates of Optimal Hedge Ratios***

As can be seen in Tables 3 and 4<sup>10</sup>, the empirical hedge ratios from the SUR and GMM estimation do not differ in a particularly dramatic way, but the standard errors of the estimates have fallen in most cases due to the substitution of the weighting matrix into the distance function. The signs of GMM estimates virtually remain the same as those of the SUR estimates, but the hedge ratios are slightly larger for the GMM estimation than for the SUR estimation. Since the GMM model provides a way to achieve *consistent* estimators in the presence of conditional heteroskedasticity, our analysis of hedge ratios will be based on the GMM estimates.

The second row of Panel A of Table 4 shows that to hedge against the variability of the deposit cost savings per unit capital that results from capital adequacy requires banks take a short position only in interest rate futures contracts for which the hedge ratio is 0.4047 with a significance level smaller than 0.05. Foreign currency futures positions are of little significance for hedging the variability due to capital adequacy. This implies that taking an appropriate hedge for the interest rate futures contracts is complete enough to minimize the risk arising from capital adequacy.

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<sup>10</sup> Some may argue that high (but not perfect) correlations among explanatory variables are likely to cause multicollinearity problem in the estimates. However, this does not impose a great deal of statistical problem on the estimates for our sake. This is because estimators for the multicollinear variables are still unbiased (and consistent) and inflated standard errors (due to the existence of multicollinearity) would have increased levels of significance; this would, in fact, only reinforce our findings of statistically significant hedge ratio coefficients.

Panel A of Table 4 reports that under the simultaneous hedging framework, the hedge ratio against the interest rate risk for interest rate futures contracts is significantly less than 1, but the hedge ratios against foreign exchange rate risks for the corresponding currency futures contracts are significantly greater than 1. The optimal (direct) hedge ratios in this study are -0.4502 for interest rate futures, -1.1496 for British pound futures, -1.2185 for Canadian dollar futures, -1.1377 for Japanese yen futures, -1.1383 for Swiss franc futures, and -1.2405 for German mark futures contracts. All of the hedge ratios are larger in magnitude than hedge ratios reported by other researchers. For example, Ederington (1979) reports that optimal hedge ratio for interest rate (T/B) futures contracts is -0.237 for two-week hedges and -0.427 for four-week hedges. Grammatikos and Saunders (1983) report that optimal hedge ratios for currency futures contracts are -0.8245 for British pound futures, -0.8376 for Canadian dollar futures, -0.7145 for Japanese yen futures, -0.9988 for Swiss franc futures, and -0.9923 for German mark futures contracts. Evidence presented here indicates that other studies on hedging (though they are concerned with hedging by individuals rather than by banks) have understated the magnitudes of short futures positions that banks should take. The evidence here shows that banks should use the futures markets to a substantially greater extent for hedging overall market risk rather than hedging each component of market risk separately. The addition to the bank's portfolio of spot positions with different characteristics provides an impetus for banks to utilize even more futures contracts.

Panel A of Table 4 also reveals that to hedge domestic interest rate risks, banks should take short positions in interest rate futures contracts and, at the same time, short positions in British pound futures contracts and long positions in German mark futures contracts as well. To hedge foreign exchange rate risks, banks should take short positions both in the interest rate futures contract and in the corresponding futures contracts

but, at the same time, long positions in some cross-currency futures contracts. This empirical evidence indicates that the hedging decisions in the presence of both interest rate and foreign exchange rate risks should consider the interdependence between domestic interest rates and foreign exchange rates (and thus with foreign currency futures rates). The significant negative correlation between interest rates and foreign exchange rates is consistent with a partial equilibrium version of the Interest Rate Parity theorem.

Panel A of Table 4 also shows that taking short positions in interest rate futures contracts is necessary to hedge foreign exchange rate risks (with the exception of Swiss franc exchange rate risk) as well as interest rate risks. While British pound futures contracts do not provide the ability to hedge overall foreign exchange rate risks other than own exchange rate risks, Japanese yen futures contracts are indispensable for hedging any of the foreign exchange rate risks. Banks with portfolios of currency positions who wanted to minimize risks during our sample period should have taken short positions in German mark futures contracts but long positions in all the other foreign currency futures contracts (with the exception of British pound futures contracts) to hedge overall foreign exchange rate risks (except for direct hedging). This could result from the German mark futures contracts being priced at a premium over the spot while other currency futures contracts were priced at a discount from the spot during our sample period [See, Thomas (1986)].<sup>11</sup> However, as can be seen in Table 10, our results show that Japanese yen, Swiss franc, and German mark futures contracts have been priced at a futures-market-premium (premium rates are 1.27%, 1.78%, and 0.96% respectively) but British pound and Canadian dollar futures contracts have been priced at

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<sup>11</sup> Thomas (1986), based on random walk simulation model, argues that a profitable currency futures trading strategy is to take long positions on currencies priced at a discount and short positions on currencies priced at a premium.

a futures-market-discount (discount rates are 3.49% and 1.31% respectively). This demonstrates evidence against Thomas' random walk currency futures trading strategy.

From Panel B of Table 4, hedging anticipatory foreign exchange rate risks requires banks take long or short positions only in cross-currency futures contracts. The corresponding futures contracts do not function as a hedging tool (at least, for an anticipatory foreign exchange rate risk). For example, to hedge the anticipatory exchange rate risk of Japanese yen spot positions, banks have to take long positions in Canadian dollar and German mark futures contracts but short positions in Swiss franc futures contracts. That is, banks are not required to take positions in Japanese yen futures contracts to hedge against the anticipatory exchange rate risk of Japanese yen. Cross-hedging is necessary to hedge anticipatory foreign exchange rate risks. Neither the interest rate nor any foreign currency futures contract is of help for hedging against anticipatory spot position on Canadian dollar. In contrast, hedging anticipatory spot position risk on British pounds requires banks take long positions in Canadian dollar futures contracts, and Japanese yen futures contracts as well as interest rate futures contracts. Notice that taking long positions in Canadian dollar futures contracts is necessary to hedge anticipatory spot positions on all foreign currencies (except for the Canadian dollar). British pound futures contracts are, again, of no help for hedging any anticipatory spot position on foreign currencies and interest rate futures contracts do not provide a hedging function against anticipatory spot position risk of foreign currencies (except for the British pound). Panel C of Table 4 shows that the situation for hedging anticipatory futures position risks of foreign currencies is, in essence, the same as that for hedging anticipatory spot position risk of foreign currencies. These results on anticipatory position hedging are novel. No other researchers have explored this

possibility either theoretically or empirically. This is an area open for much additional research to further document and explain the origins of this phenomenon.

#### 5.4.2 Results of Hypothesis Tests

Table 5 reports the values of the chi-square test statistic for the capital adequacy irrelevance hypothesis. The joint test that all  $\beta_{1j}$  for  $j = 2,3,\dots,7$  are equal to zero is a chi-square statistic with six degrees of freedom. The value of the test statistic is 14.4596 which corresponds to a significance level smaller than 0.05. This indicates that the capital adequacy irrelevance hypothesis is strongly rejected at conventional levels of significance. Hence, we report that banks and regulators should take capital adequacy into consideration when they formulate optimal futures positions. The issue of capital adequacy should play a vital role in bank hedging in futures markets.

Table 6 shows the values of the chi-square test statistic for the naive-single market hypothesis. The joint test is all  $\beta_{ij} = 0$  if  $i \neq j$  and all  $\beta_{ij} = 1$  if  $i = j$  for  $i = 2,3,\dots,7$  and  $j = 2,3,\dots,7$ . The values of the chi-square test statistic (with six degrees of freedom) are 185.5916, 93.2260, 120.8892, 53.1127, 54.1560, and 30.1646 for interest rate futures, British pound futures, Canadian dollar futures, Japanese yen futures, Swiss franc futures, and German futures contracts, respectively. All the values of the test statistic have a significance level smaller than 0.01, indicating that naive-single market hypothesis is strongly rejected at conventional levels of significance for all risks considered here. That is, it is strongly rejected that to hedge the interest rate risk, for example, banks take the interest rate futures position that is opposite in sign but at the same amount of units as the net interest revenue position. This implies that it is not optimal to take a *naive* position in the *corresponding* futures contracts to hedge a specific type of spot position.

The values of the coefficients are significantly greater than one in all cases and that certainly contributes to rejection of the naive hypothesis. Thus hedgers should take futures positions opposite but of a larger magnitude than their spot positions.

Table 7 reports the values of the chi-square test statistic for the own market hypothesis. The joint hypothesis is all  $\beta_{i,j} = 0$  if  $i \neq j$  for  $i = 2,3,\dots,7$  and  $j = 2,3,\dots,7$ . The values of the chi-square test statistic which are large in number demonstrate strong evidence against the null hypothesis that the bank takes a position only in the corresponding futures contract (but not naively). It is conventionally believed that banks should take only interest rate futures positions to hedge interest rate risks, or take only British pound futures positions to hedge foreign exchange rate risks of British pound, etc. This separate hedging strategy is strongly rejected by our empirical test. Banks must use a simultaneous, multi-contract hedging strategy whether they are hedging interest rate risk or foreign exchange rate risk. A portfolio of futures contracts should be employed even when the bank is only exposed to risk from one source. This result indicates that the naive-single market hypothesis rejects *both* because of the need for larger futures positions and the need for cross-hedging.

Table 8 presents test results of the intertemporal position hypothesis for foreign currencies. The joint hypothesis is all  $\beta_{i,j} = 0$  for  $i = 8,9,\dots,17$  and  $j = 2,3,\dots,7$ . The results show strong evidence against the null hypothesis except for Canadian dollar spot and futures positions. This implies that the bank's anticipated positions in foreign currency spot and futures contracts next period affect the current futures decisions (especially the optimal hedge ratios). When banks anticipate future foreign currency spot and futures market positions, they should hedge the uncertainty of spot and futures positions (what we called anticipatory position risk) as well as exchange rate return and

interest rate return risks. The results in table 7 only demonstrate evidence *for* the null hypothesis  $\beta_{ij} = 0$  for  $i = 8,9,\dots,17$  and  $j = 2,3,\dots,7$  in the case of Canadian dollar positions because the values of the chi-square test statistics are 6.9946 and 6.3760, respectively. One reason for this might be that the exchange rate of Canadian dollar, relative to other exchange rates, does not exhibit large variability over the long run as seen in Figures 2 and 4. This enables banks to predict long-run exchange rate movements to some extent and hedging anticipatory position risk becomes less important.

Panels A and B of Table 9 show the values of the chi-square test statistic (from employing *Wald* test) and the F-test statistic (from employing the *Chow* test), respectively, for the international banking hypothesis. The joint hypothesis for the *Wald* test is that  $\sum_{i=3}^7 \beta_{ij} = 0$  for each  $j = 1,2,\dots,7$ . The value of the chi-square test statistic with 7 degrees of freedom is 436.1293 which indicates that the null hypothesis is strongly rejected. The joint hypothesis for the *Chow* test is that  $\beta_i = \gamma_i$  for  $i = 1,2,3,\dots,7$  as described by regression equations in section 5.3.2. The value of the F-test statistic with 7 degrees of freedom for the numerator and 46 degrees of freedom for the denominator is 117.6857 which corresponds to a significance level smaller than 0.0001. Both tests show strong evidence against the null hypothesis that optimal (minimum risk) hedge ratios in the presence of international banking activity are the same as those for the domestic banking activity. This implies that international banking activity, as it is interrelated with domestic and international credit markets, should be considered when banks make decisions on optimal futures positions.

*Summary:* Optimal hedge ratio estimates reveal that the variability due to capital adequacy can be hedged by taking only interest rate futures positions; foreign currency futures positions are of little significance for hedging capital adequacy variability. Pre-

vious studies on hedging have understated the magnitudes of short futures positions that banks should take; banks should use the futures markets to a greater extent for hedging overall market risk simultaneously rather than hedging each component of market risk separately. Recognition of the interdependence between interest rates and foreign exchange rates is absolutely necessary to hedge overall market risk. Japanese yen futures contracts play a significant role in hedging overall foreign exchange rate risks, whereas British pound futures contracts are of no use for hedging overall foreign exchange rate risks other than own exchange rate risks. Hypothesis tests demonstrate evidence that the bank, when it seeks to hedge overall market risk simultaneously, should consider the factors of capital adequacy and anticipated positions to be taken in the future time period. Cross-hedging is critical for hedging anticipatory position risk and important for enhancement of hedging performance. The bank's optimal futures positions when it engages in international banking activity should be significantly different from those when they engage only in domestic banking activity. In a nutshell, our empirical results strongly support the theory developed in this study.

## **Chapter 6**

### **CONCLUSION**

This study investigates the simultaneous use of interest rate and currency futures markets to hedge the exchange and interest rate risks faced by banks. Banks in this study accept short-term variable rate deposits, hold many different foreign currencies, and make long-term fixed rate loans. Most papers have focused on the issue of either hedging interest rate risk using interest rate futures contracts or hedging foreign exchange rate risk using foreign currency futures contracts in a separate framework. The results based on an isolated analysis of only a particular risk of banking activity may not simultaneously hold true because each model is developed under a different, and often mutually exclusive, set of assumptions. The need for simultaneous management of exchange and interest rate risks faced by banks is obviated by international finance theory that the interest rate of a given currency will be influenced by the interest rate development of other currencies and by the financial market's expectations on the future foreign exchange rate of the currencies. The interdependence between movements of exchange rates and interest rates makes it important for a bank to coordinate its policies toward

risk management; banks, in practice, manage their exchange and interest rate risks as part of their overall interest rate and foreign exchange trading activities, which include both funded asset and liability positions (on-balance sheet positions) and non-funded positions (off-balance sheet positions).

This study, within a two-period framework and in the presence of multiple contracts on different instruments, sheds light on the optimal macro-hedging behavior of a risk-averse bank that hedges simultaneously its exchange and interest rate risks. We employ a two-period model because hedge positions are revised as new information is received by a bank and cash flow in one period affects the bank's ability to take advantage of opportunities in the next period. Therefore, the revelation of new information and the possession of reinvestment opportunities create another decision point and thus the situation should be intrinsically a two-period decision problem. The use of multiple contracts by banks in our model represents the fact that banks hold currency asset positions in many different currencies concurrently. This enables banks to employ cross-hedging opportunities. The use of futures contracts for hedging the overall market risk (macro-hedging) is substantiated by the general belief that it will be in the best interest of the financial intermediary's stockholders and managers to hedge its risk on a macro-basis. Market risk faced by banks is formulated in accordance with the traditional descriptions for exchange and interest rate risks. For example, short-term deposit borrowing at a random rate and the extension of long-term loans at a fixed rate creates a mismatch in maturity — interest rate risk. Taking net positions in foreign currencies when exchange rates are known and liquidating them when exchange rates are unknown creates exchange rate risk.

During the first period, profits are obtained from the interest payment from loans plus the return from holding foreign currencies plus any gains or losses in the interest rate and currency futures markets less the costs of deposits. The second period profits are obtained in the same manner with the addition of reinvestment opportunities from cash flows generated in the first period. The bank is assumed to maximize an expected utility function defined over terminal wealth for which the utility function is characterized by *constant absolute risk aversion*.

The theoretical model shows that the bank's optimal simultaneous hedge ratios for risks associated with exchange rate, interest rate, and anticipatory positions are given by the coefficients of the theoretical *multivariate* multiple regression of returns from trading the (spot) instruments being hedged on those from trading the futures contracts. This result is contrasted with that from a single hedging model in which the optimal hedge ratios are given by the coefficients of the *univariate* multiple regressions of the spot position on the futures position. Under the single hedging model, there is no mechanism through which more than two spot variables can be interrelated simultaneously. That is, it ignores any interdependence among spot variables (or implicitly assumes that other spot variables remain constant). We show that hedging interest rate risk only with interest rate futures contracts without recognition of the interdependence between interest rates and foreign exchange rates could be misleading. The amount by which the optimal interest rate futures position is misleading depends upon the extent to which spot exchange rates are correlated with interest rates.

We demonstrate that the expected return from trading futures contracts can not be zero even with the unbiasedness of interest and currency futures rates. That is, unlike extant bank hedging research, the profit opportunities in futures markets do not vanish

even though futures markets are *martingale-efficient* in removing excess profits. This is because reinvestment opportunities in the second period enable the bank to take advantage of any deviation of *ex post* first period futures return from *ex ante* zero expected futures return in the first period. This implies that the speculative component of futures demand by banks can explain one of the reasons why banks trade futures contracts at least over the long run. *Martingale-efficient* futures markets are frequently assumed by many researchers. However, this assumption does not guarantee the rationale for non-existence of speculative demand by banks.

Unlike previous studies, capital adequacy is shown in this study to be an important factor determining the bank's optimal futures position. This is because the profits generated in the first period are carried over to capital in the form of retained earnings at the start of the second period without being paid out as dividends. The losses generated in the first period are refinanced at the random deposit rate prevailing in the second period to make the new balance sheet balanced. Capital, as an alternative to variable rate short-term deposits, plays a role in reducing (increasing) maturity mismatch risk when the bank generates profits (losses) in the first period.

Comparative static analysis demonstrates that the bank's decisions on loan extensions and interest rate futures positions are affected by the existence of foreign exchange operations and the availability of foreign currency futures contracts. For example, it is shown in this study that if the net loan revenue (net of deposit costs) is expected to be zero, the bank will extend more (less) loans as CD interest rates are positively (negatively) correlated with foreign exchange rates. It is also shown that even though interest rate futures markets are characterized by *martingale-efficiency*, the bank will establish

more (less) interest rate futures position to hedge interest rate risks as interest rate futures and currency futures rates are negatively (positively) correlated.

The theoretical prescription for macro-hedging suggests that the bank should hedge the risk associated with its anticipated position in the next period in addition to exchange rate and interest rate risks whenever it expects spot and futures market positions to be taken in the future. This indicates that the (optimal) hedging decisions anticipated for later time periods influence current decisions, which implies that hedge positions are intertemporally dependent. This provides a focus on a type of risk to be hedged that has heretofore not received attention in the study of optimal hedging.

The following five testable hypotheses are derived from the theoretical analyses:

(i) Capital adequacy irrelevance hypothesis.

The null hypothesis is that capital adequacy is irrelevant for the bank's optimal hedging decisions. This hypothesis is consistent with the treatment of capital in virtually all research on hedging, but is inconsistent with the implications of the theory developed in this study.

(ii) Naive-single market hypothesis.

The null hypothesis is that hedgers should use only one futures contract for each spot instrument with positions of opposite sign but in the same amount of units as the spot instrument being hedged. The assumption is that the one futures market is complete enough to hedge a specific type of spot instrument. The theory developed in this study suggests that this hypothesis is unlikely to be validated by the

data unless spot and futures rates are perfectly correlated across contracts and there is no basis risk.

(iii) Own market hypothesis.

The null hypothesis is that only direct hedging (but not naively) is necessary to hedge a specific type of spot instrument and cross-hedging is unnecessary. Although results of previous currency futures studies suggest direct hedging strategies are effective, their approach is somewhat simplistic and overlooks the need for hedgers to implement (optimal) hedge ratio estimates that can increase hedging performance. As presented in this study, banks should employ cross-hedging opportunities, thereby increasing hedging performance.

(iv) Intertemporal position irrelevance hypothesis.

The null hypothesis is that future decisions on the spot and futures positions are irrelevant when the bank makes current optimal decisions on the spot and futures positions. One period single hedging decision models are employed by other researchers, ignoring the possibility of any relationship between time periods. The theory in this study is that current positions should account for futures positions that banks will take in a future time period.

(v) International banking hypothesis.

The null hypothesis is that optimal hedge ratios for domestic interest rate risk, for example, are the same when the bank engages in international banking activity as when it does not engage in international banking activity. The theory developed

in this study suggests that optimal hedge ratios will be different for domestic and international banks.

These hypotheses are tested using the GMM model suggested by Hansen (1982) and extended by Newey and West (1987). The use of the GMM model is necessitated by the need for the simultaneous estimation of different futures returns (due to an integrated framework of interest rate and currency futures markets in our theoretical model) and by the statistical characteristics of international financial asset returns. Returns in foreign currency spot and futures markets are shown by other researchers to exhibit substantial time-varying variance that can be represented as conditional heteroskedasticity. GMM provides a way to estimate the parameters of a system and achieve *consistent* estimators in the presence of conditional heteroskedasticity. GMM is applicable regardless of the data frequency and produces a robust estimation.

The empirical results from estimating simultaneous optimal hedge ratios using the GMM model show that the hedge ratio against the interest rate risk for interest rate futures contracts is significantly less than 1 but the hedge ratios against foreign exchange rate risks for the corresponding currency futures contracts are significantly greater than 1. Evidence presented in this study indicates that other studies on hedging have understated the magnitudes of short futures positions that hedgers should take. Banks should use the futures markets to a substantially greater extent for hedging overall market risk rather than hedging each component of market risk separately. Results also show that to hedge the interest rate risk, banks should take short positions in interest rate futures contracts and, at the same time, short positions in British pound futures contracts and long positions in German mark futures contracts as well. To hedge foreign exchange rate risks, banks should take short positions both in the interest rate futures contracts

and in the corresponding currency futures contracts but, at the same time, long positions in some cross-currency futures contracts. This empirical evidence indicates that the hedging decisions in the presence of both interest rate and foreign exchange rate risks should consider the interdependence between interest rates and foreign exchange rates (and thus with foreign currency futures rates).

We find that while Japanese yen futures contracts provide a great deal of ability and effectiveness for hedging overall foreign exchange rate risks, British pound futures contracts do not have the hedging ability of overall foreign exchange rate risks other than own exchange rate risks. Hedging anticipatory foreign exchange rate risks requires banks take long or short positions only in cross-currency futures contracts. A direct hedging strategy is of no use for hedging anticipatory foreign exchange rate risk, but cross-hedging is effective for hedging anticipatory foreign exchange rate risk. This result validates the theoretical role given to anticipated positions to be taken at a later date. Further research is warranted on the causes and consequences of this new factor in hedging decisions.

Results of hypothesis tests indicate that each hypothesis is strongly rejected at conventional levels of significance. First, the result of the capital adequacy irrelevance hypothesis test indicates strong relevance of capital adequacy in the bank's decision on optimal futures positions. Banks should consider capital adequacy when they formulate optimal futures positions. Second, the result of the naive- single market hypothesis test strongly rejects that when hedging a specific type of spot instrument, banks should take only the corresponding futures position that is opposite in sign but in the same amount of units as the instrument being hedged. It is not optimal for the bank to take a naive position in the corresponding futures contracts to hedge a specific type of spot position.

Third, the result of the own market hypothesis test shows the importance and necessity of cross-hedging by banks in futures market. Banks should use a simultaneous, multi-contract hedging strategy whether they are hedging interest rate risk or foreign exchange rate risk. A portfolio of futures contracts will, to a great extent, increase hedging performance. Fourth, the result of the intertemporal position irrelevance hypothesis test demonstrates evidence (except for the Canadian dollar position) that the bank's anticipated positions in foreign currency spot and futures contracts next period affect the current decisions on optimal spot and futures positions. Hedging anticipatory position risk of Canadian dollar is less important, perhaps due to relatively little variability of Canadian dollar during our sample period. Finally, the result of the international banking hypothesis test shows that optimal hedge ratios in the presence of international banking activity are significantly different from those for banks with activity only in domestic markets. International banking activity and the interrelationship between domestic and international credit markets should be considered even when the bank makes decisions on optimal domestic interest rate futures positions.

*In Summary*, in this dissertation, a two-period model of bank hedging activity was constructed. The contribution of the model is the theoretical development of the bank's optimal hedge positions in the face of both interest and foreign exchange rate risks and a portfolio rather than a single component of the portfolio. The empirical implications of the theory are tested using a Generalized Method of Moments (GMM) technique in order to account for conditional heteroskedasticity in the system of equations. More efficient and robust estimators are obtained for the minimum risk hedge ratios. The implications from the theoretical model regarding the relevance of capital adequacy, the importance of a portfolio approach to hedging, and the novel feature of anticipating activities in future periods all were supported by the empirical analysis.

# **Appendix A**

## **Appendix**

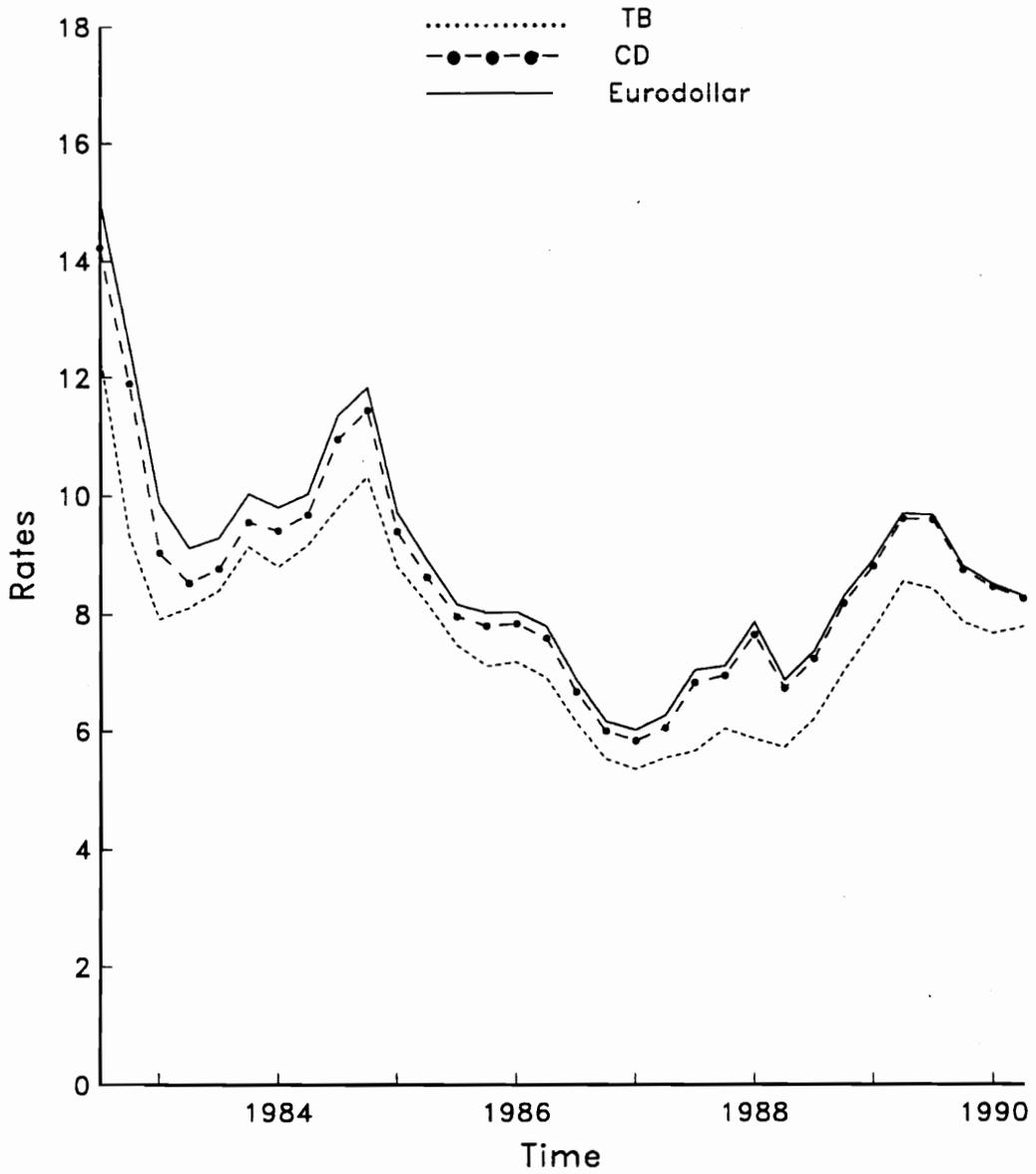
In this appendix, we provide covariance terms associated with the first order conditions of chapter 3.

$$\begin{aligned} \text{cov}(\tilde{\Pi}, \tilde{R}_l) &= K_0 \text{cov}(\tilde{R}_l, \tilde{\tau}) + L \text{var}(\tilde{R}_l) + f \text{cov}(\tilde{R}_l, \tilde{R}_f) + \text{cov}(\tilde{R}_l, \tilde{\mathbf{R}}_{c0}) \mathbf{C}_0 \\ &\quad + \text{cov}(\tilde{R}_l, \tilde{\mathbf{R}}_{F0}) \mathbf{F}_0 + \text{cov}(\tilde{R}_l, \tilde{\mathbf{R}}_{c1}) E(\tilde{\mathbf{C}}_1^*) + \text{cov}(\tilde{R}_l, \tilde{\mathbf{R}}_{F1}) E(\tilde{\mathbf{F}}_1^*). \end{aligned}$$

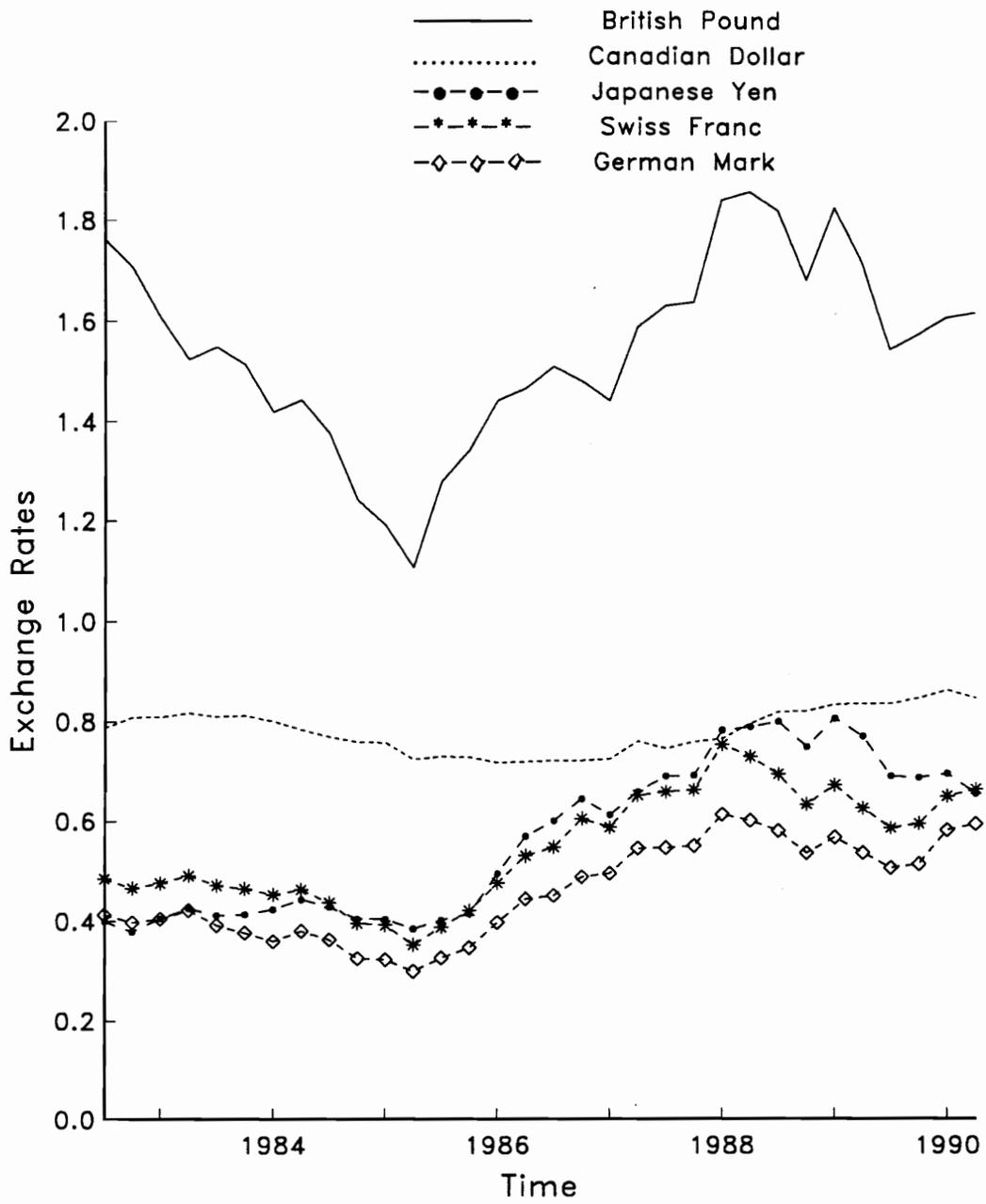
$$\begin{aligned} \text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{c0}) &= K_0 \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\tau}) + L \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{R}_l) + f \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{R}_f) + \text{var}(\tilde{\mathbf{R}}_{c0}) \mathbf{C}_0 \\ &\quad + \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{F0}) \mathbf{F}_0 + \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{c1}) E(\tilde{\mathbf{C}}_1^*) + \text{cov}(\tilde{\mathbf{R}}_{c0}, \tilde{\mathbf{R}}_{F1}) E(\tilde{\mathbf{F}}_1^*). \end{aligned}$$

$$\begin{aligned} \text{cov}(\tilde{\Pi}, \tilde{R}_f) &= K_0 \text{cov}(\tilde{R}_f, \tilde{\tau}) + L \text{cov}(\tilde{R}_f, \tilde{R}_l) + f \text{var}(\tilde{R}_f) + \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c0}) \mathbf{C}_0 \\ &\quad + \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F0}) \mathbf{F}_0 + \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{c1}) E(\tilde{\mathbf{C}}_1^*) + \text{cov}(\tilde{R}_f, \tilde{\mathbf{R}}_{F1}) E(\tilde{\mathbf{F}}_1^*). \end{aligned}$$

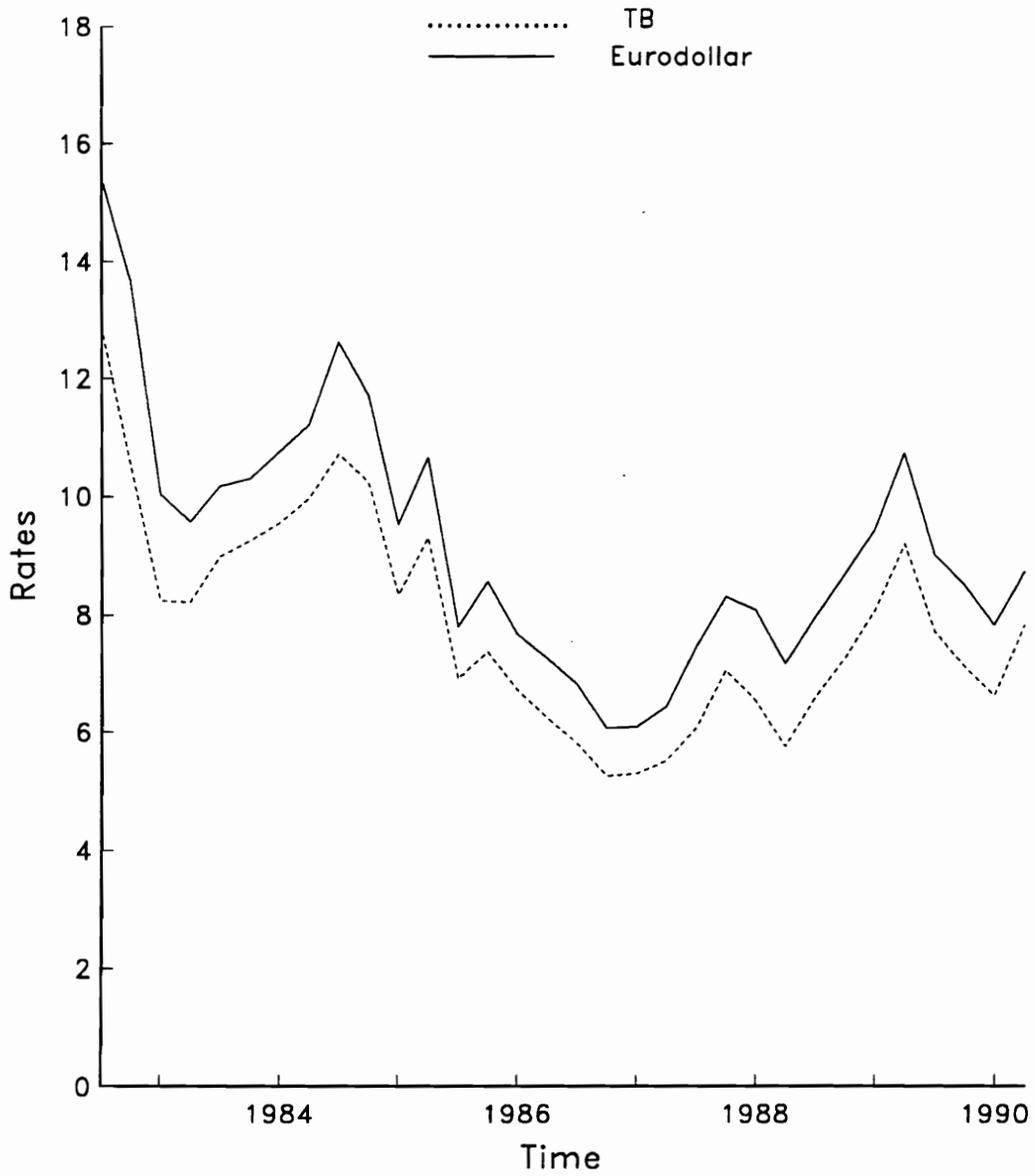
$$\begin{aligned} \text{cov}(\tilde{\Pi}, \tilde{\mathbf{R}}_{F0}) &= K_0 \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\tau}) + L \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_l) + f \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{R}_f) + \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c0}) \mathbf{C}_0 \\ &\quad + \text{var}(\tilde{\mathbf{R}}_{F0}) \mathbf{F}_0 + \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{c1}) E(\tilde{\mathbf{C}}_1^*) + \text{cov}(\tilde{\mathbf{R}}_{F0}, \tilde{\mathbf{R}}_{F1}) E(\tilde{\mathbf{F}}_1^*). \end{aligned}$$



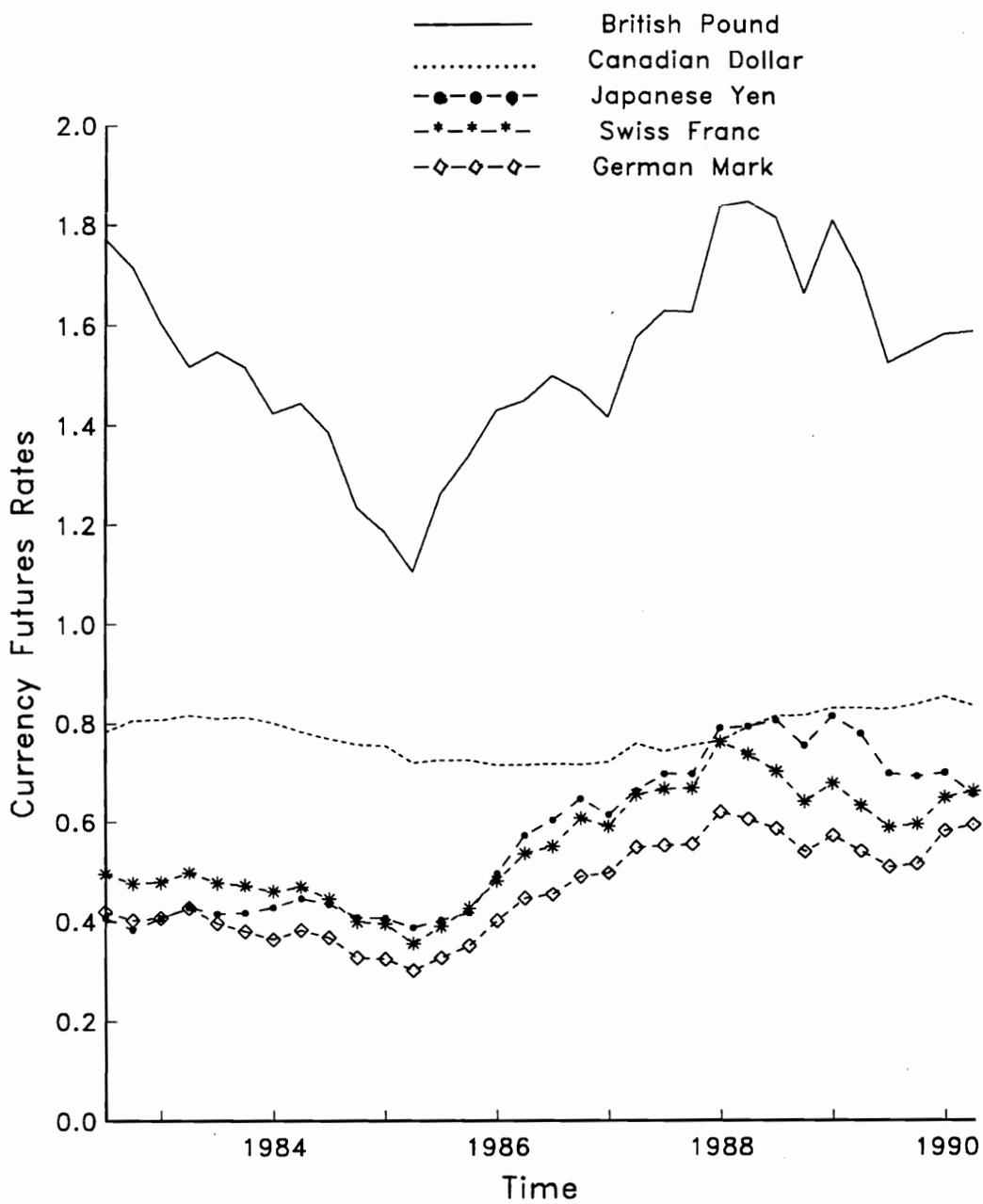
**Figure 1. Interest Rates**



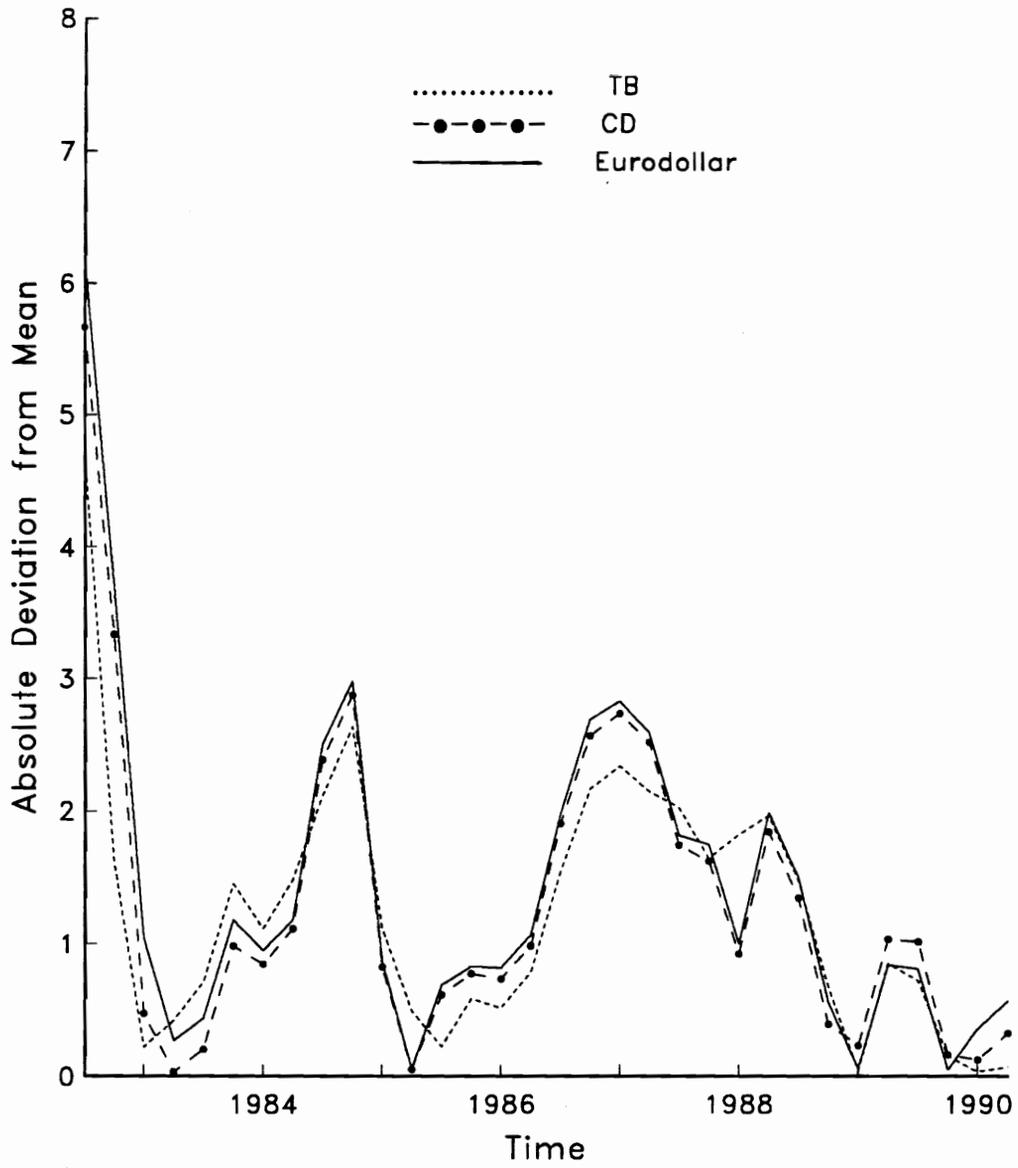
**Figure 2. Foreign Exchange Rates**



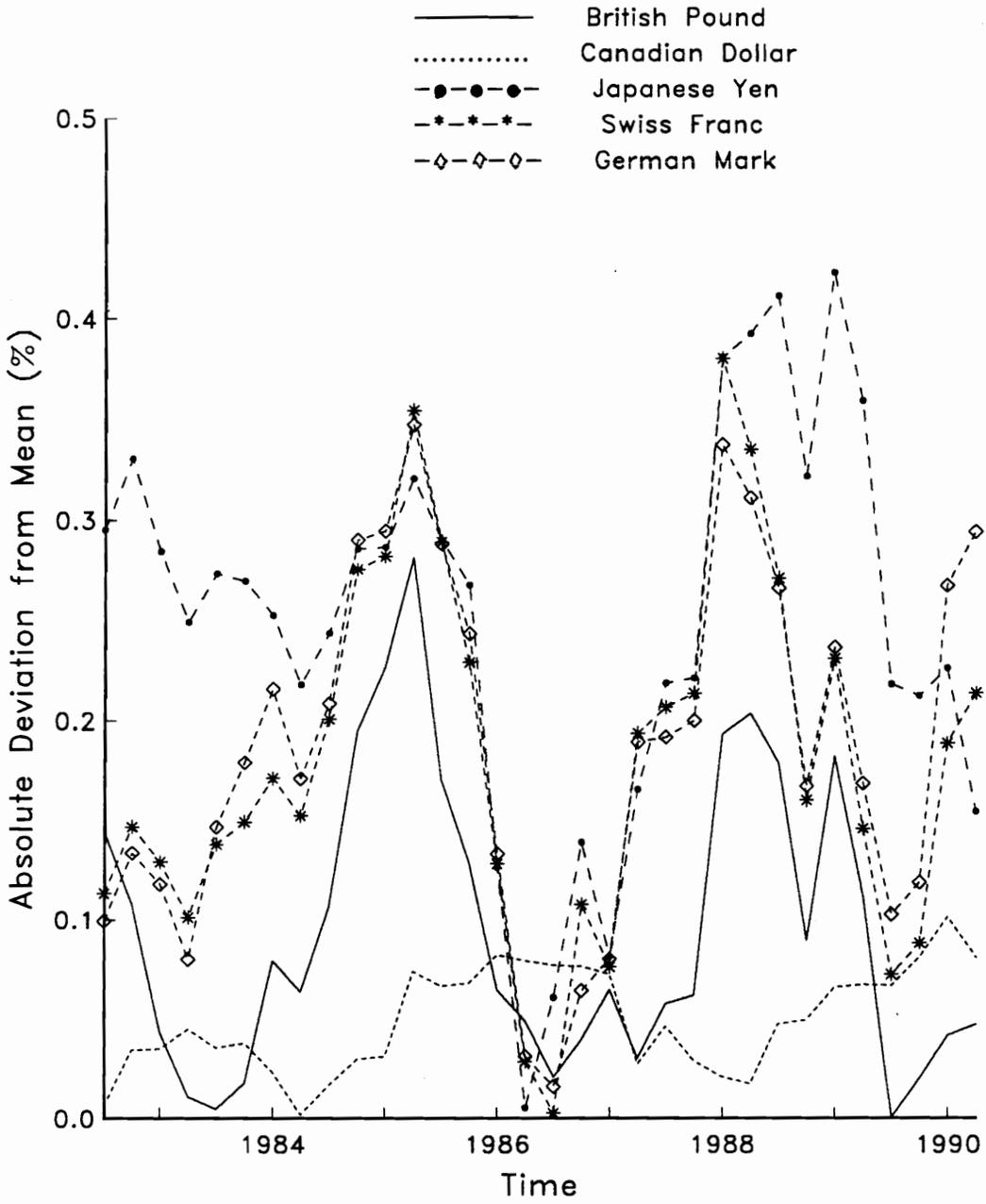
**Figure 3. Interest Rate Futures Rates (90 days)**



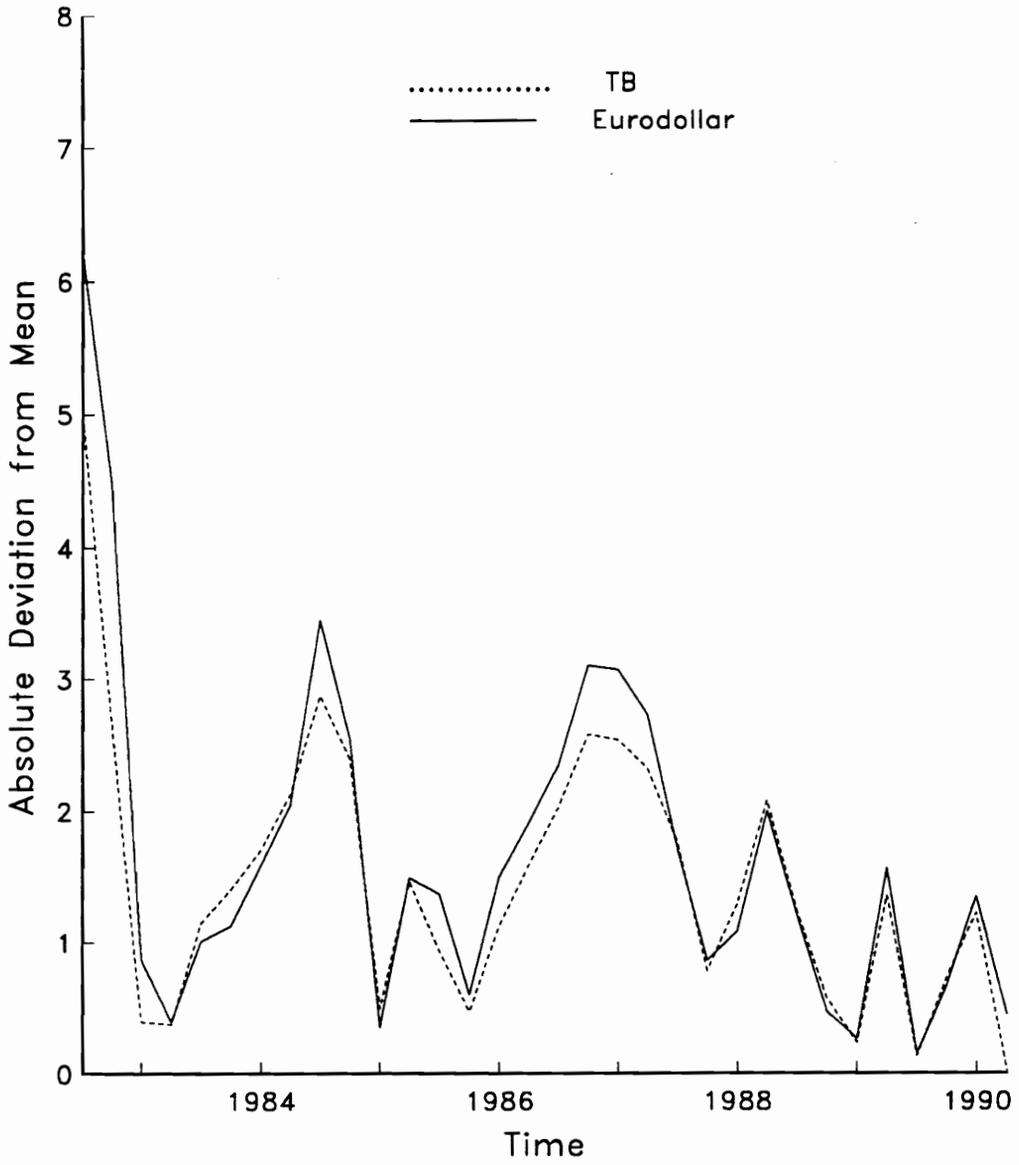
**Figure 4. Foreign Currency Futures Rates (90 days)**



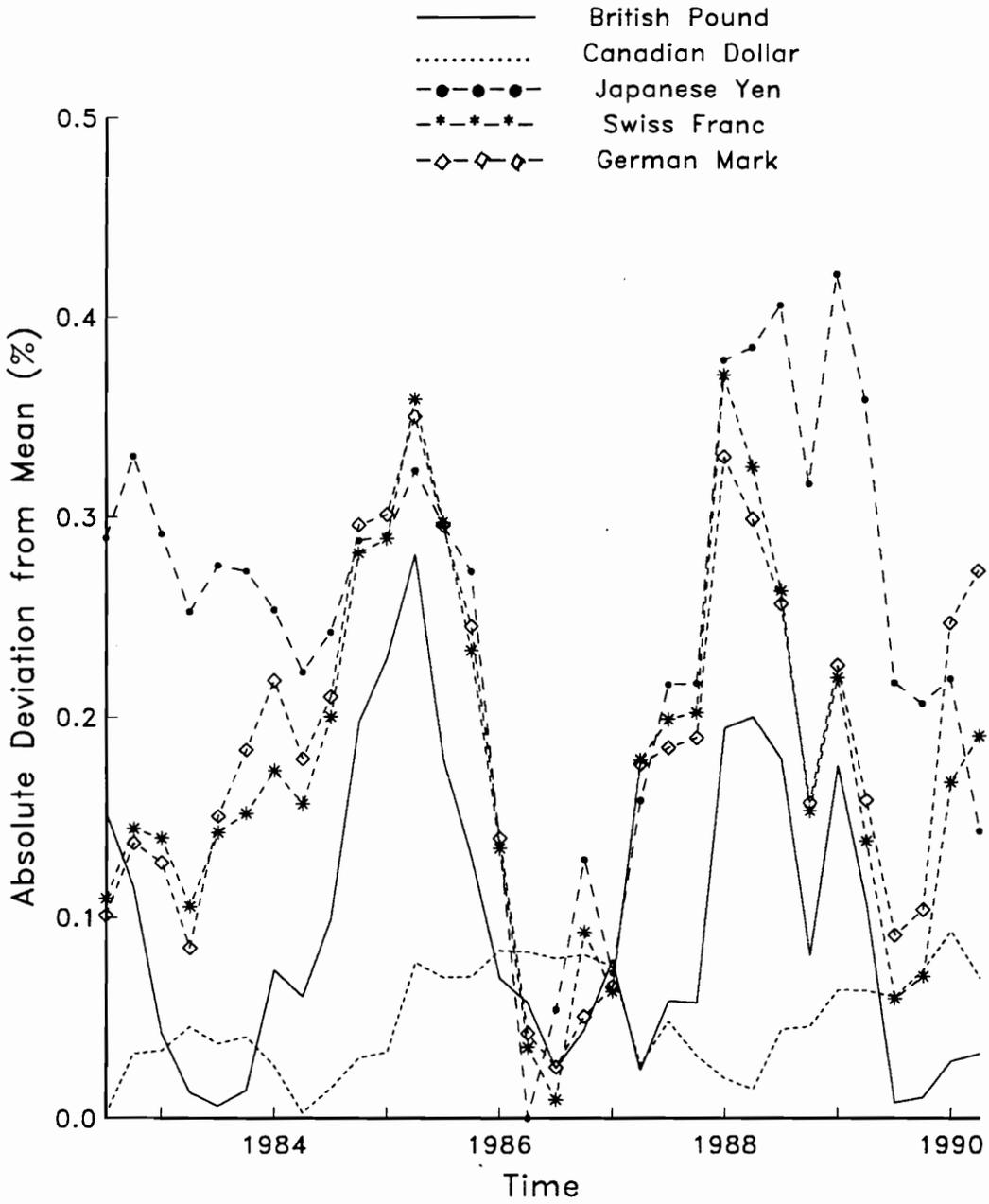
**Figure 5. Variability of Interest Rates**



**Figure 6. Variability of Foreign Exchange Rates**



**Figure 7. Variability of Interest Rate Futures Rates (90 days)**



**Figure 8. Variability of Foreign Currency Futures Rates (90 days)**

**Table 1**  
**Correlation Coefficients of Quarterly Interest and Foreign Exchange Rates**  
(the second quarter of 1982 thru the first quarter of 1990)

	T/B	C/D	Euro\$	Britain	Canada	Japan	Swiss	Germany
T/B		0.9664 (0.0001)	0.9635 (0.0001)	-0.2082 (0.2528)	0.3079 (0.0865)	-0.6086 (0.0002)	-0.6047 (0.0002)	-0.5621 (0.0008)
C/D	0.9664 (0.0001)		0.9962 (0.0001)	-0.0469 (0.7990)	0.3376 (0.0588)	-0.5117 (0.0028)	-0.4880 (0.0046)	-0.4497 (0.0098)
Euro\$	0.9635 (0.0001)	0.9962 (0.0001)		-0.0513 (0.7803)	0.3135 (0.0806)	-0.5557 (0.0010)	-0.5143 (0.0026)	-0.4794 (0.0055)
Britain	-0.2082 (0.2528)	-0.0469 (0.7990)	-0.0513 (0.7803)		0.5285 (0.0019)	0.6726 (0.0001)	0.8023 (0.0001)	0.7969 (0.0001)
Canada	0.3079 (0.0865)	0.3376 (0.0588)	0.3135 (0.0806)	0.5285 (0.0019)		0.2989 (0.0966)	0.3370 (0.0593)	0.4042 (0.0218)
Japan	-0.6086 (0.0002)	-0.5117 (0.0028)	-0.5557 (0.0010)	0.6726 (0.0001)	0.2989 (0.0966)		0.9424 (0.0001)	0.9359 (0.0001)
Swiss	-0.6047 (0.0002)	-0.4880 (0.0046)	-0.5143 (0.0026)	0.8023 (0.0001)	0.3370 (0.0593)	0.9424 (0.0001)		0.9910 (0.0001)
Germany	-0.5621 (0.0008)	-0.4497 (0.0098)	-0.4794 (0.0055)	0.7969 (0.0001)	0.4042 (0.0218)	0.9359 (0.0001)	0.9910 (0.0001)	

\* Numbers in parantheses are *p*-values.

**Table 2**  
**Correlation Coefficients of Quarterly Interest and Foreign Currency Futures Rates**  
**(90 days)**

(the second quarter of 1982 thru the first quarter of 1990)

	T/B	Euro\$	British pound	Canadian dollar	Japanese yen	Swiss franc	German mark
T/B		0.9856 (0.0001)	0.1037 (0.5659)	-0.2781 (0.1171)	0.5864 (0.0003)	0.5421 (0.0011)	0.5224 (0.0018)
Euro\$	0.9856 (0.0001)		0.0159 (0.9301)	-0.2849 (0.1081)	0.5452 (0.0010)	0.4923 (0.0036)	0.4737 (0.0054)
British pound	0.1037 (0.5659)	0.0159 (0.9301)		0.5381 (0.0012)	0.6543 (0.0001)	0.7952 (0.0001)	0.7837 (0.0001)
Canadian dollar	-0.2781 (0.1171)	-0.2849 (0.1081)	0.5381 (0.0012)		0.2961 (0.0943)	0.3603 (0.0394)	0.4200 (0.0149)
Japanese yen	0.5864 (0.0003)	0.5452 (0.0010)	0.6543 (0.0001)	0.2961 (0.0943)		0.9314 (0.0001)	0.9264 (0.0001)
Swiss franc	0.5421 (0.0011)	0.4923 (0.0036)	0.7952 (0.0001)	0.3603 (0.0394)	0.9314 (0.0001)		0.9910 (0.0001)
German mark	0.5224 (0.0018)	0.4737 (0.0054)	0.7837 (0.0001)	0.4200 (0.0149)	0.9264 (0.0001)	0.9910 (0.0001)	

\* Numbers in parantheses are *p*-values.

Table 3

Optimal Hedge Ratios from SUR Estimation

(the second quarter of 1982 through the first quarter of 1990)

Panel A

Variable	$R_f$	$R_{F0B}$	$R_{F0C}$	$R_{F0J}$	$R_{F0S}$	$R_{F0G}$
$\tau$	-0.0110 (-0.027)	-0.0432 (-0.509)	-0.4440 (-1.305)	-0.1709 (-0.753)	0.3734 (1.061)	-0.5147 (-1.260)
$R_t$	-0.3217 (-4.594)***	0.0298 (2.071)**	-0.00086 (-0.149)	0.0243 (0.632)	-0.1376 (-2.310)**	0.0945 (1.366)
$R_{CVB}$	-0.4415 (-1.128)	-1.1609 (-14.431)***	-0.2312 (-0.718)	0.4627 (2.153)**	0.6138 (1.843)*	-1.1926 (-3.082)***
$R_{CVC}$	-0.0739 (-0.672)	0.0251 (1.110)	-1.2013 (-13.268)***	0.0957 (1.583)	0.0085 (0.091)	-0.1531 (-1.408)
$R_{CVJ}$	-0.3645 (-2.841)***	0.0194 (0.736)	0.1625 (1.540)	-1.1044 (-15.684)***	-0.0742 (-0.680)	0.0036 (0.028)
$R_{CVS}$	-0.2432 (-1.282)	-0.0562 (-1.441)	0.2950 (1.890)*	0.1070 (1.027)	-0.3288 (-2.037)**	-1.0059 (-5.364)***
$R_{CVG}$	-0.1995 (-2.903)***	0.0033 (0.232)	0.0583 (1.030)	0.0898 (2.380)**	-0.0051 (-0.088)	-1.1795 (-17.366)***

\*\*\* : Statistically significant at the 1 percent level;  
 \*\* : Statistically significant at the 5 percent level;  
 \* : Statistically significant at the 10 percent level.

**Panel B**

Variable	$R_f$	$R_{F0B}$	$R_{F0C}$	$R_{F0J}$	$R_{F0S}$	$R_{F0G}$
$R_{C1B}$	0.3165 (0.187)	-0.1861 (-0.535)	0.9894 (0.711)	1.7816 (1.918)*	0.7978 (0.554)	-3.1609 (-1.890)*
$R_{C1C}$	-0.0482 (-0.155)	-0.0337 (-0.528)	-0.2074 (-0.812)	0.1384 (0.812)	0.1532 (0.580)	-0.2272 (-0.740)
$R_{C1J}$	-0.6071 (-0.853)	-0.0512 (-0.350)	0.5505 (0.941)	0.0879 (0.225)	-0.6517 (-1.077)	0.5518 (0.785)
$R_{C1S}$	-0.2509 (-0.377)	-0.0630 (-0.461)	0.6595 (1.206)	0.7866 (2.155)**	-0.2797 (-0.495)	-0.5976 (-0.910)
$R_{C1G}$	-0.2656 (-0.506)	-0.0358 (-0.332)	0.5180 (1.200)	0.5743 (1.993)**	-0.3348 (-0.750)	-0.3263 (-0.629)

\*\*\* : Statistically significant at the 1 percent level;  
 \*\* : Statistically significant at the 5 percent level;  
 \* : Statistically significant at the 10 percent level.

**Panel C**

Variable	$R_f$	$R_{F0B}$	$R_{F0C}$	$R_{F0J}$	$R_{F0S}$	$R_{F0G}$
$R_{F1B}$	0.5456 (0.365)	-0.1438 (-0.469)	0.8893 (0.724)	1.2419 (1.514)	0.6168 (0.485)	-2.3043 (-1.561)
$R_{F1C}$	-0.0405 (-0.167)	-0.0374 (-0.750)	-0.1273 (-0.638)	0.0383 (0.288)	0.1263 (0.612)	-0.0579 (-0.241)
$R_{F1J}$	-0.3142 (-0.489)	-0.0563 (-0.426)	0.2700 (0.511)	0.0189 (0.054)	-0.4165 (-0.761)	0.4409 (0.694)
$R_{F1S}$	-0.1237 (-0.206)	-0.0608 (-0.493)	0.4920 (0.997)	0.5599 (1.700)*	-0.2341 (-0.459)	-0.3900 (-0.657)
$R_{F1G}$	-0.1421 (-0.296)	-0.0333 (-0.339)	0.3927 (0.996)	0.4355 (1.655)	-0.2262 (-0.555)	-0.3040 (-0.642)

\*\*\* : Statistically significant at the 1 percent level;  
 \*\* : Statistically significant at the 5 percent level;  
 \* : Statistically significant at the 10 percent level.

**Table 4**

**Optimal Hedge Ratios from GMM Estimation**

(the second quarter of 1982 through the first quarter of 1990)

**Panel A**

Variable	$R_f$	$R_{F0B}$	$R_{F0C}$	$R_{F0J}$	$R_{F0S}$	$R_{F0G}$
$\tau$	-0.4047 (-1.993)**	-0.0012 (-0.018)	-0.3994 (-0.922)	-0.0766 (-0.337)	-0.2615 (-0.488)	0.0063 (0.022)
$R_t$	-0.4502 (-3.905)***	-0.0174 (-2.715)***	0.0383 (0.716)	0.0190 (0.632)	-0.0803 (-1.345)	0.0730 (2.579)***
$R_{C0B}$	-0.3029 (-2.554)**	-1.1496 (-22.532)***	-0.2420 (-0.796)	0.4742 (4.131)***	0.5269 (1.785)	-1.1410 (-5.388)***
$R_{C0C}$	-0.1618 (-4.413)***	0.0166 (1.170)	-1.2185 (-25.315)***	0.0681 (2.694)***	0.1513 (12.437)***	-0.2640 (-5.360)***
$R_{C0J}$	-0.4051 (-2.440)**	0.0146 (1.493)	0.1220 (8.244)***	-1.1377 (-23.403)***	0.0690 (0.470)	-0.1095 (-1.321)
$R_{C0S}$	0.2783 (0.498)	0.0030 (0.062)	0.3522 (2.926)***	0.2293 (2.188)**	-1.1383 (-12.301)***	-0.3639 (-1.736)*
$R_{C0G}$	-0.2234 (-7.434)***	0.0010 (0.087)	0.0378 (2.657)***	0.0694 (3.104)***	0.0726 (3.776)***	-1.2405 (-86.628)***

\*\*\* : Statistically significant at the 1 percent level;

\*\* : Statistically significant at the 5 percent level;

\* : Statistically significant at the 10 percent level.

**Panel B**

Variable	$R_f$	$R_{F0B}$	$R_{F0C}$	$R_{F0J}$	$R_{F0S}$	$R_{F0G}$
$R_{C1B}$	1.6327 (3.965)***	-0.0582 (-0.409)	1.1952 (2.501)**	2.1385 (9.277)***	-1.1563 (-0.913)	-1.6501 (-0.941)
$R_{C1C}$	-0.0837 (-0.253)	-0.0402 (-1.872)*	-0.1648 (-0.890)	0.1555 (1.628)	0.1128 (0.760)	-0.1877 (-1.108)
$R_{C1J}$	-0.5026 (-1.798)*	-0.0437 (-0.553)	0.5256 (2.355)**	0.0986 (0.481)	-0.7347 (-2.098)**	0.6130 (12.437)***
$R_{C1S}$	0.0050 (0.016)	-0.0039 (-0.242)	0.6082 (2.201)**	0.7912 (5.123)***	-0.4794 (-1.861)*	-0.4347 (-2.238)**
$R_{C1G}$	-0.0374 (-0.320)	-0.0120 (-0.354)	0.4936 (9.553)***	0.5937 (14.170)***	-0.5970 (-7.117)***	-0.1094 (-0.775)

\*\*\* : Statistically significant at the 1 percent level;

\*\* : Statistically significant at the 5 percent level;

\* : Statistically significant at the 10 percent level.

Panel C

Variable	$R_f$	$R_{F0B}$	$R_{F0C}$	$R_{F0J}$	$R_{F0S}$	$R_{F0G}$
$R_{F1B}$	1.5484 (3.090)***	-0.0524 (-0.755)	1.0468 (3.768)***	1.5271 (3.473)***	-0.8113 (-1.274)	-1.2332 (-1.153)
$R_{F1C}$	-0.0295 (-0.127)	-0.0401 (-2.435)**	-0.0885 (-0.595)	0.0641 (1.823)*	0.0456 (0.305)	0.0082 (0.050)
$R_{F1J}$	-0.2253 (-1.134)	-0.0518 (-0.642)	0.2624 (1.422)	0.0387 (0.323)	-0.4932 (-3.309)***	0.4893 (2.757)***
$R_{F1S}$	0.0961 (0.230)	-0.0422 (-2.496)**	0.4583 (2.221)**	0.5705 (2.747)***	-0.4073 (-0.916)	-0.2556 (-1.149)
$R_{F1G}$	0.0681 (0.424)	-0.0125 (-0.496)	0.3789 (7.896)***	0.4594 (7.201)***	-0.4705 (-2.368)**	-0.1076 (-0.915)

\*\*\* : Statistically significant at the 1 percent level;  
 \*\* : Statistically significant at the 5 percent level;  
 \* : Statistically significant at the 10 percent level.

Table 5

The Result of *Wald* Test of Capital Adequacy Irrelevance Hypothesis

$$H_0 : \text{all } \beta_{1j} = 0 \text{ for } j = 2,3,\dots,7.$$

Dependent Variable	$\chi^2$ -value	Degrees of Freedom
$\tau$	14.4596	6

Note:

$\chi^2_{(6)} = 14.449$  at the 5% significance level.

**Table 6**

**The Results of *Wald* Test of Naive-Single Market Hypothesis**

$$H_0 : \begin{cases} \text{all } \beta_{i,j} = 0 \text{ if } i \neq j \\ \text{and} \\ \text{all } \beta_{i,j} = 1 \text{ if } i = j \end{cases}$$

for  $i = 2,3,\dots,7$  and  $j = 2,3,\dots,7$ .

Dependent Variable	$\chi^2$ -value	Degrees of Freedom
$R_t$	185.5916	6
$R_{C0B}$	93.2260	6
$R_{C0C}$	120.8892	6
$R_{C0V}$	53.1127	6
$R_{C0S}$	54.1560	6
$R_{C0G}$	30.1646	6

Note:

$\chi^2_{(6)} = 14.449$  at the 5% significance level.

$\chi^2_{(6)} = 18.548$  at the 1% significance level.

**Table 7**  
**The Results of *Wald* Test of Own Market Hypothesis**

$H_0$  : all  $\beta_{i,j} = 0$  for  $i \neq j$ .  
for  $i = 2,3,\dots,7$  and  $j = 2,3,\dots,7$ .

Dependent Variable	$\chi^2$ -value	Degrees of Freedom
$R_t$	168.1732	6
$R_{C0B}$	1,991.6609	6
$R_{C0C}$	66.0716	6
$R_{C0V}$	17.2562	6
$R_{C0S}$	138.9198	6
$R_{C0G}$	906.2977	6

Note:

$\chi^2_{(6)} = 14.449$  at the 5% significance level.

$\chi^2_{(6)} = 18.548$  at the 1% significance level.

**Table 8**

**The Results of *Wald* Test of Intertemporal Position Irrelevance Hypothesis**

$$H_0 : \text{all } \beta_{ij} = 0 \quad \text{for } i = 8,9, \dots, 17 \text{ and } j = 2,3, \dots, 7.$$

Dependent Variable	$\chi^2$ -value	Degrees of Freedom
$R_{C1B}$	284.8923	6
$R_{C1C}$	6.9946	6
$R_{C1J}$	15.3195	6
$R_{C1S}$	229.7696	6
$R_{C1G}$	215.2037	6
$R_{F1B}$	22.9964	6
$R_{F1C}$	6.326	6
$R_{F1J}$	35.4799	6
$R_{F1S}$	1,175.7662	6
$R_{F1G}$	472.0029	6

Note:

$\chi^2_{(6)} = 14.449$  at the 5% significance level.

$\chi^2_{(6)} = 18.548$  at the 1% significance level.

**Table 9**

**The Test Results of International Banking Hypothesis**

**Panel A: The Result of *Wald* Test**

$$H_0: \sum_{i=3}^7 \beta_{ij} = 0 \quad \text{for each } j = 1, 2, \dots, 7.$$

Dependent Variable	$\chi^2$ -value	Degrees of Freedom
$\sum_{j=1}^5 R_{tj}$	436.1293	7

Note:

$\chi^2_{(7)} = 16.013$  at the 5% significance level.

$\chi^2_{(7)} = 20.278$  at the 1% significance level.

**Panel B: The Result of *Chow* Test**

$$H_0: \beta_1 = \gamma_1, \beta_2 = \gamma_2, \dots, \beta_7 = \gamma_7.$$

Dependent Variable	F-value	Degrees of Freedom
$R_t^{dom}$ and $R_t^{in}$	117.6857	7, 46

Note:

$F_{0.005; 7, 46} = 3.74$ .

**Table 10**  
**Currency Futures Market Premia and Discounts**  
(the second quarter of 1982 thru the first quarter of 1990)

Foreign Currency	Premium or Discount	T: mean = 0
British pound	-3.49 %	-5.6597
Canadian dollar	-1.31 %	-8.4220
Japanese yen	1.27 %	6.1944
Swiss franc	1.78 %	5.2590
German mark	0.96 %	8.1361

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