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Cross-hedging foreign interest rates with U.S. financial futures

Yen, Simon H., Ph.D.
The Ohio State University, 1989

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CROSS-HEDGING FOREIGN INTEREST RATES
WITH U.S. FINANCIAL FUTURES

DISSERTATION

Presented in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in the Graduate School of The Ohio State University

By

Simon H. Yen, B.S., M.S., M.B.A., M.A.

The Ohio State University
1989

Dissertation committee:

Rene M. Stulz
Warren B. Bailey
Stephen A. Buser

Approved by

Advisor
Graduate Program in
Business Administration
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1989
Simon H. Yen
To My Parents, Wife and Children
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April 18, 1949 .......................... Born - Chuanghua, Taiwan, R.O.C.

1971 ........................................ B.S. in Business Management,
National Cheng Kung University,
Tainan, Taiwan, R.O.C.


1975 ........................................ M.S. in Industrial Management,
National Cheng Kung University,
Tainan, Taiwan, R.O.C.

1975-Present ................................ Industrial Economics Researcher,
Industrial Technology Research
Institute (ITRI), Taiwan, R.O.C.

1982 ........................................ M.B.A., Saint Louis University,
Saint Louis, Missouri

1982-1984 .................................. Part-time Associate Professor of
Industrial Management,
National Taiwan College of
Marine Science and Technology,
Keelung, Taiwan, R.O.C.

1984-1985 .................................. One-year fellowship from
National Science Council, R.O.C.
for studying at The Ohio State
University, Columbus, Ohio.

1985-Present ................................ on leave from ITRI to be a
Graduate Research (or Teaching)
Associate,
The Ohio State University,
Columbus, Ohio.

1987 .......................................... M.A. in Finance,
The Ohio State University,
Columbus, Ohio.

FIELDS OF STUDY

Major field: Finance
Studies in International Finance, Investments and Corporate Finance

Minor field: Economics
<table>
<thead>
<tr>
<th>TABLE OF CONTENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
</tr>
<tr>
<td>VITA</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
</tr>
<tr>
<td>II. RELATED WORK</td>
</tr>
<tr>
<td>1. Hedging Domestic Interest Rates</td>
</tr>
<tr>
<td>2. The Interest Rate Parity Theorem</td>
</tr>
<tr>
<td>3. Cross-Hedging</td>
</tr>
<tr>
<td>4. Cross-Hedging Foreign Interest Rates</td>
</tr>
<tr>
<td>III. METHODOLOGY</td>
</tr>
<tr>
<td>1. Two-Period Cross-Hedging Models</td>
</tr>
<tr>
<td>2. A New Test Statistic of the Out-of-Sample Cross-Hedging Effectiveness</td>
</tr>
<tr>
<td>3. Test Hypotheses</td>
</tr>
<tr>
<td>IV. EMPIRICAL TESTS AND RESULTS</td>
</tr>
<tr>
<td>1. Data Sets</td>
</tr>
<tr>
<td>2. Empirical Results and Analyses</td>
</tr>
<tr>
<td>V. CONCLUSION</td>
</tr>
<tr>
<td>TABLES</td>
</tr>
<tr>
<td>FIGURES</td>
</tr>
<tr>
<td>REFERENCES</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Observations of Quarterly Futures Prices and Euro-Rates</td>
<td>63</td>
</tr>
<tr>
<td>2. The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Naive Hedge</td>
<td>64</td>
</tr>
<tr>
<td>3. The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures Naive Hedge</td>
<td>65</td>
</tr>
<tr>
<td>4. The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures One-Beta Hedge</td>
<td>66</td>
</tr>
<tr>
<td>5. The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Two-Beta Hedge</td>
<td>67</td>
</tr>
<tr>
<td>6. The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Three-Beta Hedge</td>
<td>68</td>
</tr>
<tr>
<td>7. The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures One-Beta Hedge</td>
<td>69</td>
</tr>
<tr>
<td>8. The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures Two-Beta Hedge</td>
<td>70</td>
</tr>
<tr>
<td>9. The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures Three-Beta Hedge</td>
<td>71</td>
</tr>
<tr>
<td>10. The Out-of-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Naive Hedge</td>
<td>72</td>
</tr>
<tr>
<td>11. The Out-of-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Optimal Hedge</td>
<td>73</td>
</tr>
<tr>
<td>12. The Out-of-Sample Cross-Hedging Effectiveness for the T-Bill Futures Naive Hedge</td>
<td>74</td>
</tr>
<tr>
<td>13. The Out-of-Sample Cross-Hedging Effectiveness for the T-Bill Futures Optimal Hedge</td>
<td>75</td>
</tr>
<tr>
<td>14. D-W Statistics</td>
<td>76</td>
</tr>
<tr>
<td>15. Correlation Coefficients Among Futures Returns</td>
<td>77</td>
</tr>
<tr>
<td>16. Correlation Coefficients Between Unhedged Interest Rates Risk and Interest Rate Futures Returns, and Total Futures Returns</td>
<td>79</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The Two-Period Cross-Hedging Scheme for the Borrowing Case</td>
<td>80</td>
</tr>
<tr>
<td>2. The Out-of-Sample Euro-British Pound Interest Rate Risk From Optimal and Naive Eurodollar Futures Hedges</td>
<td>83</td>
</tr>
<tr>
<td>3. The Out-of-Sample Euro-British Pound Interest Rate Risk From Various Optimal Eurodollar Futures Hedges</td>
<td>84</td>
</tr>
<tr>
<td>4. The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk From Optimal and Naive Eurodollar Futures Hedges</td>
<td>85</td>
</tr>
<tr>
<td>5. The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk From Various Optimal Eurodollar Futures Hedges</td>
<td>86</td>
</tr>
<tr>
<td>6. The Out-of-Sample Euro-Japanese Yen Interest Rate Risk From Optimal and Naive Eurodollar Futures Hedges</td>
<td>87</td>
</tr>
<tr>
<td>7. The Out-of-Sample Euro-Japanese Yen Interest Rate Risk From Various Optimal Eurodollar Futures Hedges</td>
<td>88</td>
</tr>
<tr>
<td>8. The Out-of-Sample Euro-Swiss Franc Interest Rate Risk From Optimal and Naive Eurodollar Futures Hedges</td>
<td>89</td>
</tr>
<tr>
<td>9. The Out-of-Sample Euro-Swiss Franc Interest Rate Risk From Various Optimal Eurodollar Futures Hedges</td>
<td>90</td>
</tr>
<tr>
<td>10. The Out-of-Sample Euro-British Pound Interest Rate Risk From Optimal and Naive T-Bill Futures Hedges</td>
<td>91</td>
</tr>
<tr>
<td>11. The Out-of-Sample Euro-British Pound Interest Rate Risk From Various Optimal T-Bill Futures Hedges</td>
<td>92</td>
</tr>
<tr>
<td>12. The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk From Optimal and Naive T-Bill Futures Hedges</td>
<td>93</td>
</tr>
<tr>
<td>13. The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk From Various Optimal T-Bill Futures Hedges</td>
<td>94</td>
</tr>
<tr>
<td>14. The Out-of-Sample Euro-Japanese Yen Interest Rate Risk From Optimal and Naive T-Bill Futures Hedges</td>
<td>95</td>
</tr>
<tr>
<td>15. The Out-of-Sample Euro-Japanese Yen Interest Rate Risk From Various Optimal T-Bill Futures Hedges</td>
<td>96</td>
</tr>
</tbody>
</table>
16. The Out-of-Sample Euro-Swiss Franc Interest Rate Risk From Optimal and Naive T-Bill Futures Hedges 97

17. The Out-of-Sample Euro-Swiss Franc Interest Rate Risk From Various Optimal T-Bill Futures Hedges 98
I. INTRODUCTION

The recent unprecedented interest rate volatility has accentuated the widespread demand by firms and bond portfolio managers to hedge interest rate risk. Domestic rates can be hedged with positions in futures contracts. For hedging foreign rates, futures contracts may not exist or may lack liquidity. Because of the Interest Rate Parity Theorem, holding a foreign bond is equivalent to holding a domestic bond plus a forward contract. Consequently, one can hedge foreign interest rate risk through forward contracts. Futures contracts are not exactly equivalent to forward contracts, but are more easily available. The question of whether one can hedge foreign interest rate risk through futures contracts traded in the U.S. is therefore an empirical question. This question is very important for firms trying to find appropriate financial instruments to hedge foreign interest rate risk since currency futures contracts are more marketable and more convenient to the hedgers than forward contracts. In this dissertation, we investigate how futures contracts can be used to hedge foreign interest rate risk.

To understand how futures contracts traded in the U.S. can be useful to hedge foreign interest rate risk, it is useful to look at an example. Consider an American firm that plans to borrow Euro-Swiss francs in 3 months for 3-month financing. Facing the volatile foreign interest rate, the firm would like to hedge the 3-month Euro-Swiss franc borrowing rate today. Since there are no Euro-Swiss franc
interest rate futures contracts, the firm sells a Eurodollar futures contract to hedge the Eurodollar interest rate. However, since Eurodollar futures are denominated in dollars, one must also hedge the exchange rate risk between dollars and the foreign currency. This can be done by transacting in the foreign exchange forward market or the foreign currency futures market. One can sell Swiss franc 90-day forward contracts to arrange to convert the foreign currency into dollars at day 90, and buy Swiss franc 180-day forward contracts to arrange to reconvert dollars into the foreign currency to pay back the Euro-Swiss franc loan at day 180, to lock in the foreign exchange rates [Kolb, Gay and Jordan 1982]. One also can buy 3-month Swiss franc futures contracts and sell 6-month Swiss franc futures contracts short to hedge the foreign exchange rates [Giddy 1983], then close out all the positions in the Eurodollar futures hedging portfolio three months later and use the futures payoff to offset the interest rate risk. Since futures contracts have characteristics such as standardized contracts, daily settlement, and minimal default risk, currency futures contracts are more attractive, more flexible and more marketable than forward contracts. Thus, the firm constructs a hedge with Eurodollar and currency futures contracts.

A hedge with Eurodollar futures contracts and two currency futures contracts is constructed to cross-hedge foreign interest rate risk. Since our futures hedging portfolio is not Eurocurrency interest rate futures, the futures payoff from cross-hedging may not exactly offset the changes in the foreign interest rate. The naive hedge, which has a hedge ratio equal to one, is not an exact hedge to
minimize foreign interest rate risk. Ederington [1979] and Franckle [1980] find that the optimal hedge, whose hedge ratios are derived from the minimum-variance model and are typically statistically significantly different from one, outperforms the naive hedge in minimizing interest rate risk. Thus, in this dissertation we construct an optimal hedging strategy with Eurodollar and currency futures.

The Interest Rate Parity Theorem (IRPT) links the foreign interest rate to the domestic interest rate through the forward exchange rate. The foreign interest rate risk of borrowing or lending in foreign currencies consists of domestic interest rate risk and foreign exchange rate risk. Numerous studies\(^1\) have examined the effectiveness of hedging domestic interest rate risk with interest rate futures and some studies have tested the effectiveness of hedging foreign exchange rate risk with currency futures. But Seymour [1985] is the only one to test empirically the effectiveness of hedging foreign interest rate risk with U.S. interest rate futures and currency futures. She finds that the foreign interest rate risk can be reduced by hedging in U.S. futures markets, but the optimal hedge doesn’t outperform the naive hedge and the Eurodollar futures hedging portfolio doesn’t work better than the T-bill futures hedging portfolio. Seymour’s first result contradicts Ederington’s [1979] and Franckle’s [1980] finding that the optimal hedge ratio is statistically significantly different from one. Her second result is more confusing to us. At first, she uses interest rate expectations
for computing the unhedged and the hedged interest rate risk, which make the comparison of the hedging effectiveness between the Eurodollar and the T-bill futures hedging portfolio more difficult. Because the unhedged interest rate risk is the difference between the actual and expected rates the different interest rate expectations will result in different unhedged interest rate risk. In other words, the different interest rate expectations cause different bases for comparison and make the comparison ambiguous. Secondly, the Eurodollar futures hedging portfolio should hedge foreign interest rate risk much better than a T-bill futures hedging portfolio because the Interest Rate Parity Theorem (IRPT) holds better in the Euromarket than in T-bill markets. Thus, Seymour's second result is contrary to the empirical evidence on the IRPT in the Euromarket.

The purpose of this dissertation is to examine the effectiveness of cross-hedging foreign interest rates with U.S. financial futures. We use the Eurocurrency interest rate implied by futures rather than interest rate expectations to compute the unhedged and the hedged foreign interest rate risk. In order to capture the time varying property of cross-hedge ratios (betas) and avoid the autocorrelation problem, which arises when autocorrelation in the error term is present and implies that the ordinary least-squares (OLS) parameter estimates are not efficient and the standard error estimates are biased, we use a rolling autoregression procedure to get the time-varying optimal cross-hedge ratios and to make adjustments to produce better estimates in these cases. Then we respectively use one
independent variable, two and three independent variables in the rolling autoregression procedure to get the estimated single-beta or multiple-betas and to detect the extent of the multicollinearity problem. In addition, we use a new test statistic of the out-of-sample cross-hedging effectiveness to compare the hedging performance between the optimal and the naive hedging strategy, between the Eurodollar and the T-bill futures hedging portfolio, and among foreign interest rates.

We find that:

(1). U.S. financial futures can be used for cross-hedging foreign interest rate risk successfully;

(2). The optimal cross-hedging strategy outperforms the naive cross-hedging strategy for the Eurodollar futures hedging portfolio. This confirms Ederington’s [1979] and Franckle’s [1980] findings in hedging domestic interest rates with new evidence from cross-hedging foreign interest rates;

(3). The Eurodollar futures hedging portfolio does cross-hedge Eurocurrency interest rates better than the T-bill futures hedging portfolio for both the optimal and the naive hedging strategy. This confirms Marston’s [1976], Herring and Marston’s [1976] and McCormick’s [1979] findings that the IRPT holds quite well in the Euromarket, but not as well when one uses T-bill markets to test.

The plan of this dissertation is as follows. Section II reviews the related works about hedging domestic interest rates, the Interest Rate Parity Theorem (IRPT), cross-hedging, and cross-hedging foreign interest rates. Section III develops two-period cross-hedging models,
defines a new test statistic of the out-of-sample cross-hedging effectiveness and proposes testing hypotheses. Empirical tests, including data sets and empirical results, are described and analyzed in Section IV. Finally, Section V provides the conclusion.
II. RELATED WORK

The focus of this paper is hedging foreign interest rates. In this section we review the literature on hedging domestic interest rates first. The difficulty in hedging foreign interest rates is the lack of appropriate futures markets for direct hedging. For example, there are no futures contracts for Euro-Swiss franc deposits to be used to hedge the foreign interest rate from borrowing or lending Euro-Swiss franc deposits. But the hedge can be done by using the cross-hedging method through the Interest Rate Parity Theorem (IRPT). For example, we can use a Eurodollar futures contract together with two Swiss franc futures contracts to hedge the Euro-Swiss franc interest rate, so that the payoff from the futures hedging portfolio offsets the changes in the Euro-Swiss franc interest rate. Thus, we review the literature on the Interest Rate Parity Theorem and then cross-hedging. Finally, we review the literature on cross-hedging foreign interest rates.

1. Hedging Domestic Interest Rates

Interest rates can be classified into short-term (maturities less than or equal to one year) and long-term. Available hedging instruments for short-term interest rates are 90-day U.S. T-bill futures, 3-month domestic CD futures, 3-month Eurodollar futures. Available hedging instruments for long-term interest rates are U.S. Treasury bond futures, U.S. Treasury note futures and GNMA (Government

7
National Mortgage Association) futures [Bacon and Williams 1976].

The objective of firms' hedging policies is risk management or risk reduction. In other words, the firms try to minimize the risk exposure by hedging policies. Why do the value-maximizing firms bother to minimize the risk exposure? Smith and Stulz [1985] answer the question by showing that a value-maximizing firm can hedge for three reasons: (1) taxes, (2) costs of financial distress and (3) managerial risk aversion. Stulz [1984] also presents a model in which value-maximizing firms pursue active hedging policies and derives optimal hedging policies for risk-averse agents.

The literature on hedging domestic interest rate risk with interest rate futures is still developing. Ederington [1979] first examines the hedging performance of financial futures markets by using a basic portfolio model (i.e., a mean-variance model or a minimum-variance model) that was previously applied to the analysis of commodity futures markets by Johnson [1960] and Stein [1961]. He finds that the optimal hedge ratio (i.e., the variance-minimizing hedge ratio) is statistically different from one (i.e., less than one) and that the short-term hedges using nearby futures contracts are more effective than the hedges using more distant contracts in T-bill futures markets. In addition, he also finds that both the GNMA and T-bill futures markets appear to be more effective in reducing the price change risk over long (four-week) than over short (two-week) periods but GNMA futures are more effective than T-bill futures. But Franckle
[1980] reexamines Ederington's model and tests by using better time-matching data and finds that the T-bill futures market appears to be more effective in reducing the price change risk over long than over short periods.

Cicchetti, Dale and Vignola [1981] reexamine Ederington's model and tests by studying interest rate changes rather than price changes and find that the T-bill futures market provides very good opportunities for hedging. Maness [1981] compares the hedging effectiveness of Ederington's optimal versus naive hedging with T-bill futures and finds that both the optimal hedging and naive hedging strategies generally reduce risk but the optimal hedging strategy doesn't outperform the naive hedging strategy.

Franckle and Senchack [1982] distinguish the anticipatory hedge (i.e., the hedge to be used for hedging expected interest rates) from the cash hedge (i.e., the hedge to be used for hedging cash positions of commodities) and develop a portfolio model of anticipatory hedging with financial futures by using interest rates rather than prices and three anticipated future spot rates, i.e. the current spot rate, the implied forward rate and the current futures rate, rather than the current spot price as in Ederington's model. They claim that the anticipatory hedge may be the most useful in the financial futures markets when we are hedging the expected interest rates, but the hedging literature developed for the commodity markets has focused primarily on situations in which one has an actual cash position or is dealing with a storable commodity.
Overdahl and Starleaf [1986] develop a portfolio model of anticipatory hedging with domestic CD futures by using two expected future spot prices, i.e., the current spot price and the implied forward price rather than the current spot price in Ederington's model and find that traditional hedges or direct hedges, i.e., CD futures hedging CDs, outperform cross-hedges, i.e., T-bill futures cross-hedging CDs. They also indicate that the choice of a proxy for the expected future spot price can be important in evaluating hedging performance and show that the implied forward price is used as a proxy better than the current spot price.

In addition to Ederington's [1979] mean-variance or basic portfolio model to minimize the variance of expected returns, Kolb and Chiang [1981 and 1982], Gay and Kolb [1983], and Gay, Kolb and Chiang [1983] develop the duration hedging model (or the price sensitivity model) to hedge domestic interest rates with interest rate futures. Using Kolb and Chiang's duration hedging model as a starting point, Hilliard [1984] constructs minimum-variance hedge ratios for a portfolio of financial futures to the spot portfolio rather than one single futures contract to the spot contract.

Most of the literature on hedging deals with two-period models. However, Stulz [1984] derives a continuous-time model for a firm's optimal hedging foreign exchange exposure through forward contracts on foreign currencies. Geske and Piepelea [1987] develop a continuous-time, stochastic model for controlling domestic interest rate risk with Treasury bond futures.
2. The Interest Rate Parity Theorem (IRPT)

There are two kinds of interest rate parity theorems in international finance literature: Uncovered Interest Rate Parity and Covered Interest Rate Parity. Uncovered Interest Rate Parity states that the nominal interest rate differential between similar securities denominated in different currencies must equal the expected percent change of the exchange rate over the holding period. Covered Interest Rate Parity states that the nominal interest rate differential between similar securities denominated in different currencies must equal the forward premium of foreign exchange [Cumby and Obstfeld 1984]. In this dissertation we focus on Covered Interest Rate Parity, and omit the reference to "covered" without concern for ambiguity.

Previous studies analyze persisting deviations from the Interest Rate Parity Theorem in terms of transaction costs [Branson 1969], political risk [Aliber 1973], and capital market imperfections [Prachowny 1970 and Frenkel 1973]. Frenkel and Levich [1975, 1977 and 1981] estimate the transaction cost from the triangular arbitrage method and show that the transaction costs account for most of deviations from the IRPT (97% for T-bill pairs and 100% for Euromarket pairs) and that empirical data are consistent with the IRPT in the sense that the covered interest arbitrage does not seem to entail unexploited profit opportunities. Marston [1976] and Herring and Marston [1976] find that the IRPT holds very well in the Eurodollar and Eurocurrency (Euro-British pound, Euro-Deutsche mark and Euro-Swiss franc) markets and attribute the close linkage of Eurodollar interest rates and Eurocurrency interest rates to the absence of
government restrictions and the absence of default risk in the Euromarket.

McCormick [1979] uses Frenkel and Levich's triangular arbitrage method and a higher-quality data set (Reuters data) to test the validity of the IRPT, and finds that the hypothesis that most of the discrepancies from the IRPT can be explained by transaction costs does not hold for T-bill pairs but the hypothesis holds very well for Euromarket pairs.

Dooley and Isard [1980] use a simple model of portfolio behavior to examine the interest differentials in the German case and confirm Aliber's [1973] notion that political risk associated with prospective capital controls can lead to deviations from the IRPT. Otani and Tiwari [1981] study the effect of capital controls in the Japanese case and find that the deviations from the IRPT for Euromarket pairs are randomly distributed around a zero mean and that the deviations from the IRPT for T-bill pairs are systematically and significantly different from zero owing to the capital controls. Cosandier and Lang [1981] test the validity of the IRPT and find that the IRPT holds better for Euromarket pairs than for T-bill pairs. In summary, these three results clearly support Aliber's [1973] hypothesis which suggests by-passing the political risk problem by using interest rates on Euro-deposits, instead of T-bill rates, to perform the empirical IRPT tests.

Browne [1983] uses a spectral analysis to test the IRPT in the Irish case and finds that in general the IRPT does not hold well. Browne uses three-month interest rates of the Dublin inter-bank, the
London inter-bank, Eurodollar deposits and Euro-Deutsche mark deposits as pairs of the IRPT test. Obviously, the pairs chosen by Browne are not identical in terms of political risk. Thus, Browne's result is consistent with Alib's [1973] notion that the IRPT does not hold when the securities used are not identical in terms of political risk.

Clinton [1988], using Reuters data like McCormick's [1979], estimates the transaction costs directly from the swap market rather than from Frenkel and Levich's triangular arbitrage method and finds smaller deviations from the IRPT than previous estimates. Although Clinton finds that transaction costs might not account entirely for observed deviations from the IRPT in the Euromarket he concludes that empirically, profitable trading opportunities are neither large enough nor long-lived enough to yield a flow of excess returns over time to any factor.

In summary, the Interest Rate Parity Theorem holds to within a very narrow transaction cost tolerance in the Euromarket (Adler and Dumas [1983], and Cumby and Obstfeld [1984]).

All the previous studies except one test the validity of the IRPT with forward prices of foreign exchange. Panton and Joy [1978] test the IRPT with the actual and implied futures prices of foreign exchange for T-bill pairs and find that the IRPT does not hold in domestic markets. Panton and Joy's result is consistent with the previous studies with forward exchange prices in T-bill markets. However, Panton and Joy do not test the IRPT with currency futures prices in the Euromarket as suggested by Aliber.
Cornell and Reinganum [1981] examine the differences between forward and futures prices from foreign exchange markets and find that the mean differences are insignificantly different from zero, both in a statistical and in an economic sense. Their results are consistent with Cox-Ingersoll-Ross's [1981] model because the relevant covariance is so small that forward and futures prices should be indistinguishable in equilibrium. Hodrick and Srivastava [1987] support Cornell and Reinganum's [1981] results by finding that there is very little difference between foreign currency futures prices and forward exchange prices on days when they can be compared.

In summary, foreign currency futures contracts are not exactly equivalent to foreign exchange forward contracts, but they are quite close. Therefore, the validity of using foreign currency futures prices instead of forward prices in the IRPT for Euromarket pairs is an empirical question. The fact that the two are quite close also suggests that currency futures can be helpful to cross-hedge foreign interest rates. This motivates an investigation of whether it is so in this dissertation.
3. Cross-Hedging

By definition, cross-hedging is the hedging of a cash position in one commodity by using the futures market for a different but related commodity. Besides being used to hedge the commodities which have no futures market, cross-hedging is also used when existing futures markets do not provide sufficient liquidity for direct hedging. Anderson and Danthine [1981] first develop a minimum-variance model of cross-hedging with multiple futures contracts and conclude that the proportion of futures which should be hedged in each contract is given by the coefficient of the theoretical multiple regression of cash prices on all futures prices. In other words, the optimal cross-hedge ratios may be calculated in exactly the same way as a standard hedge in Ederington's [1979] model.

When the appropriate futures markets do not exist the cross-hedging method can be used. Miller and Luke [1982] investigate whether cross-hedging with live cattle futures offers food service institutions the opportunity to reduce their exposure to wholesale beef price risk and find that cross-hedging is apparently an effective risk management tool. Kuberek and Pefley [1983] evaluate the cross-hedging effectiveness of Treasury bond futures to reduce the price risk of corporate debt and find that Treasury bond futures offer substantial protection against unexpected changes in corporate bond prices and nearer Treasury bond futures contracts are superior to more distant contracts in cross-hedging corporate debt. Grieves [1986] finds that money managers can cross-hedge the portfolio of corporate bonds more effectively using a combination of Treasury bond futures
and stock index futures than they can cross-hedge using Treasury bond futures only. Eaker and Grant [1987] examine the cross-hedging effectiveness of German mark futures contracts to reduce the price risk of a Spanish peseta cash position and find that cross-hedging is less effective than traditional direct hedging, but on the whole cross-hedging is shown to be a useful risk reduction technique. Eaker and Grant also point out that three factors determine the measured effectiveness of cross-hedges: the true correlation between assets, the accuracy of estimates of the risk-minimizing hedge ratios and the stability of the true hedge ratio over time.

When the existing futures markets do not provide sufficient liquidity for direct hedging, it often becomes worthwhile to cross hedge. Senchack and Easterwood [1983] examine the cross-hedging effectiveness of T-bill futures (rather than direct hedging with CD futures) to reduce the interest rate risk of domestic CDs and find that cross-hedging reduces the borrowing cost and the associated risk. Saunders and Sienkiewicz [1988] analyze the direct hedging performance of the ECU (European currency unit) futures market on the International Monetary Market, Chicago Mercantile Exchange as a direct hedging tool for ECUs and the cross-hedging effectiveness of a portfolio consisting of pound and mark futures contracts as a cross-hedging tool for ECUs and find that there is very little statistical difference in the hedging effectiveness. This is why holders of a cash position in European currencies and ECUs may well prefer to use the deeper and more liquid futures markets in pounds and marks rather than turning to the new futures market of ECUs.
4. Cross-Hedging Foreign Interest Rates

The U.S. financial futures markets (U.S. T-bill futures and Eurodollar futures markets) are the largest short-term interest rate futures markets in the world. Since all contracts in U.S. interest rate futures markets are denominated in U.S. dollars, it appears that potential hedgers of foreign interest rate risk have no readily available way of directly hedging that risk. Obviously, cross-hedging is the only way of managing foreign interest rate risk.

Kolb, Gay and Jordan [1982] use a simple numerical example to show how investors with foreign interest rate risk can use U.S. interest rate futures to cross-hedge that risk, by trading the correct combination of U.S. 3-month domestic CD futures in conjunction with appropriate forward transactions in the foreign exchange market. They define the expected foreign interest rate as the implied forward rate from the IRPT in T-bill markets. There are two weakness in Kolb, Gay and Jordan's model of cross-hedging foreign interest rates: (1) The CD futures market is not sufficiently liquid (Cornell [1981], Senchack and Easterwood [1983]); (2) The IRPT doesn't hold in T-bill markets.

The IRPT holds quite closely in the Euromarket, as discussed earlier, and the 3-month Eurodollar futures market and the 90-day U.S. T-bill futures market are sufficiently liquid. Obviously, the best interest rate candidates for testing the cross-hedging effectiveness are the Eurodollar and Eurocurrency interest rates (rather than T-bill rates) and the best U.S. interest rate futures for cross-hedging Eurocurrency interest rates are 3-month Eurodollar futures or 90-day U.S. T-bill futures. Giddy [1983], also using a very simple numerical
example, shows that cross-hedging Eurocurrency interest rates can be accomplished by means of U.S. financial futures contracts. Giddy suggests that this can be done by using a Eurodollar futures contract (to hedge the future dollar interest rate) together with two foreign currency futures contracts (to hedge the exchange rates at which the currency is initially sold and subsequently bought). Thus the Eurocurrency interest rate implied by futures is the difference between the Eurodollar futures contract yield and the foreign currency swap rate.

The only empirical test of cross-hedging foreign interest rates is done by Seymour [1985]. Seymour, using Ederington's minimum-variance model, evaluates the extent to which U.S. financial futures can be used to cross-hedge Eurocurrency interest rate risk and finds that the use of U.S. financial futures can reduce that risk, but neither the naive hedging strategy nor the minimum-variance hedging strategy emerge as clearly preferable to the other and the Eurodollar futures hedging portfolio doesn't outperform the T-bill futures hedging portfolio.

The puzzles raised by Seymour are that Ederington's minimum-variance hedging strategy doesn't outperform the naive hedging strategy and that the IRPT doesn't hold better in the Euromarket than in T-bill markets. Seymour's mixed results contradict Ederington's [1979] and Franckle's [1980] findings that the optimal hedge ratio is statistically significantly different from one, and the supportive evidence of the IRPT in the Euromarket. There are three problems in Seymour's tests: (1) The main problem is that she defines the
interest rate risk as the difference between the actual and the expected Eurocurrency interest rate defined as either the forward interest rate, or the interest rate implied by the Interest Rate Parity Theorem. The interest rate expectations cause her to compare the hedging effectiveness in different bases and make the comparisons difficult; (2) She uses two independent variables (the gain or loss on the interest rate futures contract, and the gain or loss on the two currency futures contracts) to run the rolling regression procedure, but fails to run an autoregression procedure to avoid the autocorrelation problem and to use one independent variable (the total return of three futures contracts) and three independent variables (the return of interest rate futures contracts, the return of 3-month currency futures contracts and the return of 6-month currency futures contracts) to detect the extent of the multicollinearity problem; (3) She uses root-mean-square errors (RMSE) in basis points (absolute scale) to compare the hedging performance of the Eurodollar futures hedging portfolio with that of the T-bill futures hedging portfolio between interest rate expectations and foreign interest rates, but fails to make comparisons by cross-hedging effectiveness in percentage reduction (relative scale).
III. METHODOLOGY

Since all U.S. interest rate futures contracts are denominated in U.S. dollars the only way to hedge foreign interest rate risk with U.S. interest rate futures is through cross-hedging. In this section we develop our two-period cross-hedging models and then we will define a new test statistic of the out-of-sample cross-hedging effectiveness. Finally, we propose our test hypotheses.

1. Two-Period Cross-Hedging Models

The Interest Rate Parity Theorem means that the interest rate differentials between similar securities in the domestic and foreign markets are equal to the foreign exchange forward premium. In other words, the Eurocurrency interest rate implied by forward prices is the difference between the Eurodollar interest rate and the foreign currency "swap rate" (the percentage forward differential relative to the spot rate). The Eurocurrency interest rate implied by forward prices is computed as follows:

\[ r_t^{EC} = r_t^{ED} - \left( \frac{G_t - S_t}{S_t} \right) \times 4 \]

then

\[ r_t^{GEC} = r_t^{ED} - \left( \frac{G_t - S_t}{S_t} \right) \times 4 \] (1)
where \( r_{EC}^t \) - the annual value of quarterly Eurocurrency interest rates at \( t \),
\( r_{EC}^{GEC} \) - the annual value of quarterly Eurocurrency interest rates implied by forward prices at \( t \),
\( r_{ED}^t \) - the annual value of quarterly Eurodollar interest rates at \( t \),
\( G_t \) - the 90-day forward price of foreign currency in terms of dollars at \( t \),
\( S_t \) - the spot price of foreign currency in terms of dollars at \( t \),
\( (G_t-S_t)/S_t \) - the quarterly foreign currency swap rate.

Suppose one American firm plans to borrow 3-month Eurocurrency deposits in 3 months (at \( t+1 \)) and wants to cross-hedge foreign interest rate risk with the futures hedging portfolio now (at \( t \)), then closes out all the positions in the futures portfolio three months later (at \( t+1 \)). The two-period cross-hedging scheme for the borrowing case is depicted in Figure 1.

For example, the firm decides to borrow Euro-Swiss francs on September 1, 1987 for 3-month financing on June 1, 1987. On September 1, 1987, the actual 3-month Euro-Swiss franc borrowing rate is 3.75% (\( r_{t+1}^{ESF} \)). The firm will borrow Euro-Swiss francs with the interest rate at 3.75% and sell Swiss francs in the spot exchange market on September 1, 1987. After 3 months the firm will buy Swiss francs in
the spot exchange market and pay back the Euro-Swiss franc loan, including the principal and the accrued interest, on December 1, 1987.

If the Eurodollar interest rate is unexpectedly high in three months the borrower of Euro-dollars has a potential loss from the interest rate increase. When the Eurodollar interest rate rises, the Eurodollar futures price falls. The owner of Eurodollar futures contracts faces the potential loss from the futures price decrease. The loss from borrowing Euro-dollars in 3 months is equivalent to the loss from buying Eurodollar futures contracts now and selling them three months later. Since the futures price will be the spot price at maturity, the return (gain or loss) from selling Swiss francs in 3 months is equivalent to the return (gain or loss) from selling 3-month Swiss franc futures contracts short now and buying them three months later. By the same token, the return from buying Swiss francs in 6 months is equivalent to the return from buying 6-month Swiss franc futures contracts now and selling them three months later. Because of the Interest Rate Parity Theorem, the Euro-Swiss franc interest rate is equal to the Eurodollar interest rate minus the foreign currency swap rate. Therefore, the return on borrowing Euro-Swiss francs in three months is equivalent to the return from buying a 3-month Eurodollar futures contract, selling a 3-month Swiss franc futures contract and buying a 6-month Swiss franc futures contract now and closing out all the positions in the futures portfolio in three months. In other words, the futures portfolio consists of long 3-month Eurodollar futures contracts, short 3-month Swiss franc futures contracts and long 6-month Swiss franc futures contracts and
corresponds to the cash position in borrowing Euro-Swiss francs in three months.

Since taking delivery of futures contracts at maturity is impossible for Eurodollar futures (because of the cash settlement) and the maturity date on the third Wednesday of the contract month cannot match the firm's borrowing need on September 1, 1987, the firm should not hold the futures portfolio (i.e., the long position of the futures portfolio) to maturity to try to lock in the foreign interest rate. On the contrary, the firm would like to take opposite positions in the futures portfolio (i.e., the short position of the futures portfolio) now (on June 1, 1987) and close out all the positions on September 1, 1987 to hedge Euro-Swiss franc interest rates.

Because the firm is exposed to both domestic interest rate risk and foreign exchange rate risk in the spot markets the firm needs to cross-hedge the risk with the futures hedging portfolio of interest rate futures and currency futures. Since the futures portfolio is regarded as a single futures contract in this dissertation, when the firm wants to cross-hedge foreign interest rates it needs to take opposite positions in the futures portfolio (i.e., the short position of the futures portfolio) as the traditional hedging strategy did. Thus, hereafter, taking positions in the futures hedging portfolio means taking opposite positions in the futures portfolio as shown in Figure 1. The firm sells September Eurodollar futures (3-month) short at 92.17, buys September Swiss franc futures (3-month) at $0.6644 and sells December Swiss franc futures (6-month) short at $0.6703 on June 1, 1987 (at time t). Then on September 1, 1987 (at
time \( t+1 \) the firm will close out the positions in the futures hedging portfolio by buying September Eurodollar futures (0-month) at 92.67, selling September Swiss franc futures (0-month) at $0.6700 and buying December Swiss franc futures (3-month) at $0.6762. The return from the futures portfolio, 0.23%, will offset the Euro-Swiss franc interest rate risk (without hedging), 0.53%, on September 1, 1987 (at time \( t+1 \)), thus the interest rate risk with naive hedging is only 0.30%. The detail of the computations is explained in Figure 1.

If futures contracts were forward contracts we could lock in the \( t+1 \) Eurocurrency interest rate at \( t \) by using the futures portfolio. Unfortunately, futures contracts are not exactly equivalent to forward contracts. The \( t+1 \) Eurocurrency interest rate calculated from the futures portfolio is not a guaranteed rate. It is only an implied rate. That's why we still need to cross-hedge foreign interest rates using the futures hedging portfolio. But the Eurocurrency interest rate implied by futures can work as a benchmark for computing foreign interest rate risk.

The \( t+1 \) i-th Eurocurrency interest rate implied by futures

\[
FEC_{i,t+1} = \left[100 - F_{ED}^E(t,1)\right] - \left[\left(F_{i}^{C}(t,2) - F_{i}^{C}(t,1)\right)/F_{i}^{C}(t,1)\right]\times100
\]  

(1')

\( FED \)
where \( r_{i,t+1}^{\text{FEC}} \) = the annual value of the quarterly i-th Eurocurrency interest rate implied by futures when taking opposite positions in the futures portfolio at \( t \),

\( F^{\text{ED}}(t,1) \) = 3-month Eurodollar futures prices (points of 100%) at \( t \),

\([100 - F^{\text{ED}}(t,1)]\) = the annual value of quarterly Eurodollar futures contract yield by selling Eurodollar futures contracts at \( t \),

\( F^{G}(t,1) \) = 3-month i-th currency futures prices ($ per foreign currency) at \( t \),

\( F^{G}(t,2) \) = 6-month i-th currency futures prices ($ per foreign currency) at \( t \),

\([(F^{G}(t,2) - F^{G}(t,1))/F^{G}(t,1)]\) = the quarterly foreign currency swap rate by buying 3-month and selling 6-month i-th currency futures contracts at \( t \).

We can find the similarity of computations between the Eurocurrency interest rate implied by forward prices defined in equation (1) and the \( t+1 \) Eurocurrency interest rate implied by futures defined in equation \((1')\). Both of them are the difference between the Eurodollar interest rate and the foreign currency swap rate. The main difference is that the former is the current (at \( t \)) guaranteed rate
26

and is computed from spot and forward prices but the latter is the future (at \( t+1 \)) implied rate and is computed from futures prices.

From now on, the futures portfolio consists of long 3-month Eurodollar futures contracts, short 3-month currency futures contracts and long 6-month currency futures contracts in our two-period cross-hedging models. The total return of the futures portfolio is composed by the following three elements: (1) the return from buying 3-month Eurodollar futures contracts now and selling them in three months; (2) the return from selling 3-month currency futures contracts short and buying them in three months; and (3) the return from buying 6-month currency futures contracts now and selling them in three months.

In order to match the borrowing date and avoid the impossibility of taking delivery on Eurodollar futures contracts the firm should take the opposite positions in the futures portfolio now and close them out in three months to cross-hedge the foreign interest rate risk. The realized borrowing interest after closing out the positions in the futures hedging portfolio at \( t+1 \) \( r_{i,t+1}^{EC} \) is the accrued interest at \( t+1 \) \( (X_{i,t+1}^{EC} r_{i,t+1}^{HEC}) \) minus the payoff (gain) from the futures portfolio \( (X_{i,t+1}^{F} F_{i,t+1}) \) as in equation (2). In other words, the realized i-th Eurocurrency interest rate from the futures hedge at \( t+1 \) \( (r_{i,t+1}^{HEC}) \) is the actual i-th Eurocurrency interest rate without hedging \( (r_{i,t+1}^{EC}) \) plus the return of the futures hedging portfolio \( (b_{i,t+1}^{F} F_{i,t+1}) \) as in equation (3). Its computation is as follows:
FECsetting b t+1 hedge ratio = -F t+1/F

then

where

XEC i,t+1 holdings of spot positions of i-th Eurocurrency deposits at time t+1,

X F i,t+1 holdings of futures positions of interest rate futures and currency futures at time t+1,

r HEC i,t+1 the quarterly realized i-th Eurocurrency interest rate from the futures hedge after closing out positions in the futures hedging portfolio at t+1,

r EC i,t+1 the quarterly actual i-th Eurocurrency interest rate at t+1,

r F i,t+1 the annual return of the quarterly futures portfolio after closing out the positions at t+1

r IRF t+1 the annual return of the quarterly interest rate futures contract by buying it at t and selling it at t+1.
\[ r_{CF3}^{1,t+1} = \left(\frac{\left[F^{C}(t,1) - F^{C}(t+1,0)\right]}{F^{C}(t,1)}\right) \times 100, \]

the quarterly return of the 3-month 1-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \)

\[ r_{CF6}^{1,t+1} = \left(\frac{\left[F^{C}(t,1) - F^{C}(t+1,1)\right]}{F^{C}(t,2)}\right) \times 100, \]

the quarterly return of the 6-month 1-th currency futures contract by buying it at \( t \) and selling it at \( t+1 \)

\[ F^{IR}(t,1) = 3\text{-month interest rate futures prices (points of 100\%)} \text{ at } t, \]

\[ F^{IR}(t+1,0) = 0\text{-month interest rate futures prices (points of 100\%)} \text{ at } t+1, \]

\[ F^{C}(t,1) = 3\text{-month 1-th currency futures prices ($ per foreign currency) at } t, \]

\[ F^{C}(t+1,0) = 0\text{-month 1-th currency futures prices ($ per foreign currency) at } t+1, \]

\[ F^{C}(t,2) = 6\text{-month 1-th currency futures prices ($ per foreign currency) at } t, \]

\[ F^{C}(t+1,1) = 3\text{-month 1-th currency futures prices ($ per foreign currency) at } t+1. \]
There are two interest rate futures used in this dissertation: Eurodollar futures (EDF) and U.S. T-bill futures (TBF). The futures hedging portfolio including Eurodollar futures is called the "Eurodollar futures hedging portfolio" and the one including U.S. T-bill futures is called the "T-bill futures hedging portfolio" in this dissertation.

If the futures hedging portfolio behaves exactly like a forward contract and perfectly hedges the Eurocurrency interest rate risk, the realized Eurocurrency interest rate from the futures hedge, which is the difference between the actual Euro-rate and gains from the futures hedging portfolio, should be identical to the Eurocurrency interest rate implied by futures. In other words, the interest rate risk, which is the difference between the realized Euro-rate from the futures hedge and the Euro-rate implied by futures, with perfect hedging should be always zero. The degree to which futures contracts diverge from forward contracts reduces the effectiveness of the hedge. Thus, the Eurocurrency interest rate implied by futures is the benchmark for computing the interest rate risk without hedging and the interest rate risk with hedging. The smaller the interest rate risk with hedging, i.e., the deviations of the realized Eurocurrency interest rate from the Eurocurrency interest rate implied by futures, the more effective is the hedging strategy.

The interest rate risk without hedging \( (e_{i,t+1}^U) \) is defined as the difference between the actual \( i \)-th Eurocurrency interest rate and the \( i \)-th Eurocurrency interest rate implied by futures. When the actual
rate is higher (lower) than the implied rate, the borrower has a potential loss (gain) in the absence of hedging. The unhedged interest rate risk for the $i$-th Eurocurrency deposit is represented by the following equation:

$$e_{i,t+1}^U = e_{FEC}^i - r_{EC}^i$$  \hfill (4)

The variance of the unhedged interest rate risk is:

$$\text{Var}(e_{i,t+1}^U) = \text{Var}(e_{FEC}^i - r_{EC}^i)$$  \hfill (5)

Since the Eurocurrency interest rate implied by futures is not a guaranteed rate the borrower is motivated to hedge the foreign interest rate. Thus the borrower will try to find the optimal hedging strategy to minimize foreign interest rate risk.

The interest rate risk with hedging ($e_{i,t+1}^H$) is defined as the difference between the realized $i$-th Eurocurrency interest rate from the futures hedge and the $i$-th Eurocurrency interest rate implied by futures. When the realized rate is lower (higher) than the implied rate, the borrower has a potential gain (loss) from futures hedging. The hedged interest rate risk for the $i$-th Eurocurrency deposit is represented by the following equations:

$$e_{i,t+1}^H = e_{FEC}^i - r_{FEC}^i - r_{EC}^i$$  \hfill (6a)
The hedging strategies considered in this dissertation are the naive hedging strategy \((b=1)\) and the optimal hedging strategy \((b>1)\), where \(b\) is derived by minimizing the variance of \(e^H\). The hedged interest rate risk for the \(i\)-th Eurocurrency deposit is represented by \(e^N_{i,t+1}\) (replacing \(N\) for \(H\) in equation (6a)) for the naive hedging strategy and by \(e^O_{i,t+1}\) (replacing \(O\) for \(H\) in equation (6a)) for the optimal hedging strategy.

The variance of the hedged interest rate risk is:

\[
\text{Var}(e^H_{i,t+1}) = \text{Var}((r^\text{FEC}_{i,t+1} - r^\text{EC}_{i,t+1}) - b_{i,t+1}r^F_{i,t+1})
\] (7a)

\[
\text{Var}(e^H_{i,t+1}) = \text{Var}(r^\text{FEC}_{i,t+1} - r^\text{EC}_{i,t+1}) + b_{i,t+1}^2 \text{Var}(r^F_{i,t+1}) - 2b_{i,t+1} \text{Cov}(r^\text{FEC}_{i,t+1} - r^\text{EC}_{i,t+1}, r^F_{i,t+1})
\] (7b)
The perfect hedge means that the realized $i$-th Eurocurrency interest rate from the futures hedge is exactly the same as the $i$-th Eurocurrency interest rate implied by futures, or that the hedged interest rate risk is equal to zero. In mathematical form the perfect hedge means that:

\[ H_{EC} = F_{EC} \]

\[ r_{i,t+1} + r_{i,t+1} \]

(8a)

or

\[ e_{i,t+1} = r_{i,t+1} - r_{i,t+1} = 0 \]

(8b)

Of course, the perfect hedge also implies that the variance of the hedged interest rate risk is equal to zero, i.e. \( \text{Var}(e^H_{i,t+1}) = 0 \).

If the futures hedging portfolio cannot perfectly hedge the $i$-th Eurocurrency interest rate risk the hedged interest rate risk should be distributed randomly around zero, i.e. \( E(e^H_{i,t+1}) = 0 \), and \( \text{Var}(e^H_{i,t+1}) > 0 \). The smaller the \( \text{Var}(e^H_{i,t+1}) \), the better is the hedging strategy.

In order to find the optimal hedging strategy to minimize the variance of the hedged foreign interest rate risk we derive the optimal hedge ratio \( (b^*_t) \) by using Ederington's [1979] minimum-variance model as follows.
The first-order condition for this problem is:

\[
\text{Min. } \text{Var}(e_{1,t+1}^H) = \text{Var}(r_{1,t+1}^{\text{FEC}} - r_{1,t+1}^{\text{EC}}) + b_{1,t+1}^2 \text{Var}(r_{1,t+1}^F) - 2b_{1,t+1} \text{Cov}([r_{1,t+1}^{\text{FEC}} - r_{1,t+1}^{\text{EC}}], r_{1,t+1}^F)
\]

The first-order condition for this problem is:

\[
d\text{Var}(e_{1,t+1}^H)/db_{1,t+1} = 2b_{1,t+1} \text{Var}(r_{1,t+1}^F) - 2\text{Cov}([r_{1,t+1}^{\text{FEC}} - r_{1,t+1}^{\text{EC}}], r_{1,t+1}^F) = 0
\]

The optimal cross-hedge ratio \((b_{1,t+1}^*)\) is exactly equal to the slope coefficient of regression:

\[
b_{1,t+1}^* = \frac{\text{Cov}([r_{1,t+1}^{\text{FEC}} - r_{1,t+1}^{\text{EC}}], r_{1,t+1}^F)}{\text{Var}(r_{1,t+1}^F)}
\]

The cross-hedging effectiveness (CHE) is measured by the percent reduction in the hedged interest rate risk. In other words, cross-hedging effectiveness is one minus the variance ratio of the hedged interest rate risk on the unhedged interest rate risk. Actually the cross-hedging effectiveness is exactly equal to the correlation coefficient of regression \((\rho_1^2)\). The proof is as follows:

\[
\text{CHE} = [\text{Var}(e_{1,t+1}^U) - \text{Var}(e_{1,t+1}^{H*})]/\text{Var}(e_{1,t+1}^U)
\]
The regression model for equations (9c) and (10c) is:

\[
(r_{\text{FEC}}_{i,t+1} - r_{\text{EC}}_{i,t+1}) = \alpha + \beta_{i,t+1}r_{i,t+1} + u_{i,t+1}
\]

or

\[
e_{i,t+1}^U = \alpha + \beta_{i,t+1}(r_{\text{IRF}}_{i,t+1} + 4r_{\text{CF3}}_{i,t+1} + 4r_{\text{CF6}}_{i,t+1}) + u_{i,t+1}
\]
2. A New Test Statistic of The Out-Of-Sample Cross-Hedging Effectiveness

In order to evaluate the out-of-sample cross-hedging effectiveness properly we introduce Meese and Rogoff's [1983a, 1983b and 1988] measure of out-of-sample fit. Their out-of-sample accuracy is measured mainly by the root mean square error (RMSE). It is defined with our notation as follows:

\[
\text{RMSE for hedged return} = \sqrt{\frac{1}{N} \sum_{t=1}^{N} (e_{t+1}^H)^2/N}^{1/2} \\
\text{RMSE for unhedged return} = \sqrt{\frac{1}{N} \sum_{t=1}^{N} (e_{t+1}^U)^2/N}^{1/2}
\]

These two statistics are the mean hedged and the mean unhedged interest rate risk (in basis points), not the percentage of risk reduction (in %), so they are not objective criteria to be used for comparing the cross-hedging effectiveness among different Eurocurrency interest rates. Because the unhedged interest rate risk (in basis points) is different among Eurocurrency interest rates and between interest rate expectations Seymour [1985] has improperly used these two statistics for comparison.

In this dissertation we define the cross-hedging effectiveness as the percentage of risk reduction. In other words, the cross-hedging effectiveness is equal to one minus the ratio of the mean cross-hedged interest rate risk to the mean unhedged interest rate risk and is
measured by a new test statistic: $C_{HE_{RMSE}}$. The new test statistic is defined as follows:

$$C_{HE_{RMSE}} = 1 - \frac{RMSE\text{ for hedged return}}{RMSE\text{ for unhedged return}} \quad (13a)$$

or

$$C_{HE_{RMSE},i} = 1 - \frac{\left(\frac{\sum_{t=1}^{N}(e_{i,t+1})^2}{N}\right)^{1/2}}{\left(\frac{\sum_{t=1}^{N}(e_{i,t+1})^2}{N}\right)^{1/2}} \quad (13b)$$

This new test statistic in equation (13b) is similar to the cross-hedging effectiveness in equation (10b) but they are not the same measurement. The relationship between $R_{1}^{2}$ and $C_{HE_{RMSE},i}$ is derived as follows:

$$R_{1}^{2} = 1 - \frac{Var(e_{i,t+1}^{H*})}{Var(e_{i,t+1}^{U})} \quad (10b)$$

$$= 1 - \frac{\sum_{t=1}^{N}(e_{i,t+1}^{H*} - E(e_{i,t+1}^{H*}))^2/N}{\sum_{t=1}^{N}(e_{i,t+1}^{U} - E(e_{i,t+1}^{U}))^2/N} \quad (14a)$$

Assume $E(e_{i,t+1}^{H*}) = E(e_{i,t+1}^{U}) = 0$, i.e., when $e_{i,t+1}^{H*}$ and $e_{i,t+1}^{U}$ are distributed randomly around zero, the equation (14a) becomes the equation (14b).

$$R_{1}^{2} = 1 - \frac{\sum_{t=1}^{N}(e_{i,t+1}^{H*})^2/N}{\sum_{t=1}^{N}(e_{i,t+1}^{U})^2/N} \quad (14b)$$

$$= 1 - \left(\frac{\sum_{t=1}^{N}(e_{i,t+1}^{H*})^2/N}{\sum_{t=1}^{N}(e_{i,t+1}^{U})^2/N}\right)^{1/2}\left(\frac{\sum_{t=1}^{N}(e_{i,t+1}^{U})^2/N}{\sum_{t=1}^{N}(e_{i,t+1}^{H*})^2/N}\right)^{1/2} \quad (14c)$$
Assume $e_{i,t+1}^{H*} - e_{i,t+1}^H$, i.e., when the optimal hedge is the naive hedge, we insert the equation (13b) into the equation (14c) and get the equation (14d).

$$R_i^2 = 1 - [1 - \text{CHE}_{\text{RMSE},i}]^2$$  \hspace{1cm} (14d)

If the two assumptions, i.e., the interest rate risk of the one-beta optimal hedge and the naive hedge is distributed around zero and the optimal hedge is the naive hedge, don't hold well the correlation coefficient ($R_i^2$) will be much different from the root-mean-squared-error cross-hedging effectiveness ($\text{CHE}_{\text{RMSE},i}$).
3. Test Hypotheses

As discussed previously, we use the foreign interest rate implied by futures for computing the unhedged and the hedged foreign interest rate risk. The autocorrelation in the time series of the ex post interest rate risk after hedges causes the parameter estimates to be inefficient and the standard error estimates to be biased, which affects the significance tests of parameter estimates. The multicollinearity of highly correlated independent variables causes the parameter estimates to be insignificantly different from zero. In order to avoid the autocorrelation problem of time series and to detect the effect of the multicollinearity problem of highly correlated independent variables we run an autoregression procedure with one independent variable (total gains or losses on the interest rate futures contract and two foreign currency futures contracts), two independent variables (the return of the interest rate futures contract, and the return of two currency futures contracts) and three independent variables (the return of the interest rate futures contract, the return of the 3-month currency futures contract, and the return of the 6-month currency futures contract). Recently, Meese and Rogoff [1983a, 1983b and 1988], Somanath [1986] and Chiang [1988] use the rolling regression procedure to capture the time-varying property of exchange rate. Seymour [1985] uses the rolling regression procedure to capture the time-varying property of hedge ratios. In this dissertation we use the rolling autoregression procedure to get the time-varying cross-hedge ratios ($b'$s) and to avoid the autocorrelation problem simultaneously. The rolling procedure in our
dissertation and Seymour's paper is different from that of Meese and Rogoff's, Somanath's, and Chiang's. Owing to the smaller sample size we use expanded sample sets (adding one more current observation to the previous run) but they use constant-size sample sets (adding one more current observation and delete the most distant observation to the previous run). In addition, we compare the out-of-sample cross-hedging effectiveness using a new test statistic, i.e., CHERMSE.

We use a 3-month Eurodollar or 90-day U.S. T-bill futures contract together with two foreign currency futures contracts on the International Monetary Market, Chicago Mercantile Exchange to cross-hedge London's Eurocurrency interest rates, such as Euro-British pound, Euro-Deutsche mark, Euro-Japanese yen and Euro-Swiss franc interest rates. The two cross-hedging strategies considered in this dissertation are the naive cross-hedging strategy (b=1) and the optimal cross-hedging strategy (b<1). Since the Interest Rate Parity Theorem holds quite well in the Euromarket but not as well in T-bill markets, the price changes of the Eurodollar futures portfolio should correlate with the unhedged interest rate risk more closely than those of the T-bill futures portfolio. Obviously, the Eurodollar futures hedging portfolio should cross-hedge foreign interest rate risk better than the T-bill futures hedging portfolio. Furthermore, from the findings of Ederington [1979] and Franckle [1980] we know that the optimal hedging strategy should cross-hedge foreign interest rate risk better than the naive hedging strategy. Thus, our maintained hypothesis in this dissertation is that the optimal hedging strategy
of the Eurodollar futures hedging portfolio can cross-hedge Eurocurrency interest rate risk better than the naive hedging strategy of the Eurodollar futures hedging portfolio and the naive and optimal hedging strategies of the T-bill futures hedging portfolio.

The maintained hypothesis consists of two test hypotheses as follows:

(Hypothesis 1) The optimal hedging strategy outperforms the naive hedging strategy for the Eurodollar futures hedging portfolio. In other words, the optimal hedge ratio ($b^*$) should be statistically significantly different from one and the out-of-sample cross-hedging effectiveness ($CHE_{RMSE}$) from the optimal hedging strategy should be better than that from the naive hedging strategy for the Eurodollar futures hedging portfolio.

(Hypothesis 2) The Eurodollar futures hedging portfolio cross-hedges foreign interest rate risk better than the T-bill futures hedging portfolio for both the optimal and naive hedging strategies. In other words, the cross-hedging effectiveness of the in-sample fit ($R^2$) and the out-of-sample fit ($CHE_{RMSE}^{*}$) from the Eurodollar futures hedging portfolio should be higher than those from the T-bill futures hedging portfolio for both the optimal and naive hedging strategies.
IV. EMPIRICAL TESTS AND RESULTS

1. Data Sets

The contract months for 90-day U.S. T-bill futures, 3-month Eurodollar futures, British pound futures, Deutsche mark futures, Japanese yen futures and Swiss franc futures in International Monetary Market, Chicago Mercantile Exchange are March, June, September and December. The first delivery day for Eurodollar futures (by cash settlement), British pound futures, Deutsche mark futures, Japanese yen futures and Swiss franc futures are all on the third Wednesday of the contract months. But the first delivery day of the T-bill futures contract is the issue date of the 13-week T-bill coinciding with the last 13 weeks of the one-year T-bill [Chicago Mercantile Exchange 1986], which is mostly on Thursday. For example, in 1986 the four delivery days of T-bill futures are on March 13, June 5, September 24 and December 17.

In our 3-month cross-hedging 3-month Eurocurrency interest rates model, we arbitrarily choose March 1, June 1, September 1 and December 1 as the day to take the positions of the futures hedging portfolio in order to close out the positions of the same existing futures contracts exactly three months later. All the quarterly 0-month, 3-month and 6-month futures settlement prices data of T-bill futures, Eurodollar futures, British pound futures, Deutsche mark futures, Japanese yen futures and Swiss franc futures in International Monetary Market, Chicago Mercantile Exchange are collected from the Wall Street
Journal. The quarterly offered and bid interest rates of Eurocurrency and Eurodollar deposits in London on the above taking and closing out
days are collected from the Financial Times (London). But sometimes
March 1, June 1, September 1 and December 1 are not business days both
in Chicago and in London, then we choose the prior nearest business
days in both cities as possible as we can. Because our futures price
data are from Chicago but our Euro-rate data are from London we have a
non-synchronous data problem.

The various time periods for the available data collected are as
follows:

(1). The quarterly Eurodollar, Euro-British pound, Euro-Deutsche
mark and Euro-Swiss franc rates are collected from March 1, 1976 to
December 1, 1987. But the quarterly Euro-Japanese yen rates are not
available until September 1, 1978.

(2). The quarterly futures price data of T-bill, British pound and
Swiss franc are collected from June 1, 1976 to December 1, 1987. But
the quarterly Deutsche mark futures price data are collected from
December 1, 1976 to December 1, 1987. The quarterly Japanese yen
futures price data are collected from June 1, 1977 to December 1,
1987. However, the quarterly Eurodollar futures price data are not
available until June 1, 1982.

Table 1 displays the period and the number of observations
collected in this dissertation. We can find that there is no
consistent number of observations among the futures prices and Euro-
rates. Thus, when we examine the cross-hedging effectiveness of
different futures hedging portfolios and different foreign interest
rates we get different number of observations. For instance, when we want to cross-hedge Euro-swiss franc interest rates by using T-bill futures contracts and two Swiss franc futures contracts, we get 47 observations. But when we want to cross-hedge Euro-Swiss franc interest rates by using Eurodollar futures contracts and two Swiss franc futures contracts, there are only 23 observations available. If we are going to cross-hedge Euro-Japanese yen interest rates by using T-bill futures contracts and two Japanese yen futures contracts, we find 38 observations. But when we want to cross-hedge Euro-Japanese yen interest rates by using Eurodollar futures contracts and two Japanese yen futures contracts, there are only 23 observations suitable for analysis.

In order to get the Eurocurrency interest rates implied by Eurodollar and currency futures prices for computing interest rate risk, we use only 23 observations in all cases for empirical tests throughout this dissertation.
2. Empirical Results and Analyses

The cross-hedging effectiveness of the naive and optimal hedging strategies of Eurodollar futures contracts or T-bill futures contracts together with two currency futures contracts for hedging Eurocurrency interest rates, such as Euro-British pound rates, Euro-Deutsche mark rates, Euro-Japanese yen rates and Euro-Swiss franc rates, is examined both in-sample and out-of-sample tests. Somanath (1986) re-examines Meese and Rogoff's (1983a, 1983b) results about empirical exchange rate models considering both the in-sample and the out-of-sample forecasting performance. Somanath claims that the benefit is that any consistency in out-of-sample and in-sample tests would improve the evidence. Meese and Rogoff (1983a, 1983b) have considered the out-of-sample performance only. Recently, Meese and Rogoff (1988) investigate the empirical relationship between real interest rate differentials and real exchange rates considering both in-sample and rolling regression out-of-sample tests. Thus, we consider both the in-sample and out-of-sample cross-hedging effectiveness in this dissertation.

In empirical tests we use one independent variable (the total return of interest rate futures contracts and two currency futures contracts), two independent variables (the return of interest rate futures contracts, and the total return of two currency futures contracts), and three independent variables (the return of interest rate futures contracts, the return of 3-month currency futures contracts, and the return of 6-month currency futures contracts) in our rolling autoregression procedure to detect the effect of the
multicollinearity problem. Those regression models in our empirical tests are:

(1) For one independent variable (or the one-beta optimal hedge),

\[ e_{i,t+1}^U = \alpha + \beta_{i,t+1}^{\text{IRF}} (r_{i,t+1}^{\text{IRF}} + 4r_{i,t+1}^{\text{CF3}} + 4r_{i,t+1}^{\text{CF6}}) + u_{i,t+1} \]  
\[ (15a) \]

(2) For two independent variables (or the two-beta optimal hedge),

\[ e_{i,t+1}^U = \alpha + \beta_{i,t+1}^{\text{IRF}} (r_{i,t+1}^{\text{IRF}}) + \beta_{i,t+1}^{\text{CF3}} (4r_{i,t+1}^{\text{CF3}} + 4r_{i,t+1}^{\text{CF6}}) + u_{i,t+1} \]  
\[ (15b) \]

(3) For three independent variables (or the three-beta optimal hedge),

\[ e_{i,t+1}^U = \alpha + \beta_{i,t+1}^{\text{IRF}} (r_{i,t+1}^{\text{IRF}}) + \beta_{i,t+1}^{\text{CF3}} (4r_{i,t+1}^{\text{CF3}}) + \beta_{i,t+1}^{\text{CF6}} (4r_{i,t+1}^{\text{CF6}}) + u_{i,t+1} \]  
\[ (15c) \]

When the optimal hedge is used, the ex post interest rate risk is:

(1) For the one-beta optimal hedge,

\[ e_{i,t+1}^0 = e_{i,t+1}^U - b_{i,t+1} (r_{i,t+1}^{\text{IRF}} + 4r_{i,t+1}^{\text{CF3}} + 4r_{i,t+1}^{\text{CF6}}) \]  
\[ (16a) \]

(2) For the two-beta optimal hedge,

\[ e_{i,t+1}^2 = e_{i,t+1}^U - b_{i,t+1}^{\text{IRF}} (r_{i,t+1}^{\text{IRF}}) - b_{i,t+1}^{\text{CF}} (4r_{i,t+1}^{\text{CF3}} + 4r_{i,t+1}^{\text{CF6}}) \]  
\[ (16b) \]
(3) For the three-beta optimal hedge,

\[ e^{3}_{i,t+1} = e^{U}_{i,t+1} - b^{i}_{t+1}(r^{IRF}_{t+1}) + b^{CF3}_{t+1}(r^{CF3}_{i,t+1}) - b^{CF6}_{t+1}(r^{CF6}_{i,t+1}) \]

(16c)

As to the naive hedge its ex post interest rate risk is:

\[ e^{N}_{i,t+1} = e^{U}_{i,t+1} - (r^{IRF}_{t+1} + r^{CF3}_{i,t+1} + r^{CF6}_{i,t+1}) \]

(16d)

(1). The In-Sample Cross-Hedging Effectiveness

The in-sample naive cross-hedging effectiveness measured by the root mean squared error (CHE_{RMSE}) for a Eurodollar or a T-bill futures contract together with two corresponding currency futures contracts is presented in Table 2 and Table 3. From the naive hedged interest rate risk (e^{N}) of the Eurodollar futures hedge in Table 2 and the T-Bill futures hedge in Table 3 the mean errors are much different from the mean absolute errors for Euro-British pound rates and Euro-Japanese yen rates, but not for Euro-Deutsche mark rates and Euro-Swiss franc rates. This implies that in general the naive hedge model systematically under-hedges or over-hedges. Comparing the in-sample naive cross-hedging effectiveness (CHE_{RMSE}) we find that the Eurodollar futures hedging portfolio can cross-hedge Eurocurrency
interest rate risk better than the T-bill futures hedging portfolio in all cases.

The Durbin-Watson statistics from the ordinary least-squares (OLS) regression model are presented in Table 14. We find that the D-W statistics are not close to 2.0 in most of cases. In other words, the time series data show the presence of first-order autocorrelation. When autocorrelation is present, the ordinary least-squares (OLS) parameter estimates are not efficient and the standard error estimates are biased. The SAS AUTOREG procedure makes adjustments to produce better estimates in these cases. Parameter estimates produced by PROC AUTOREG are usually similar to ordinary least-squares estimates, but the standard errors can be very different, affecting significance tests. In order to overcome the significance test problem of autocorrelation and find efficient parameter estimates for hedging we run the AUTOREG procedure with two lags.

The in-sample optimal cross-hedging effectiveness ($R^2$) and optimal cross-hedge ratios ($b$'s) are the computer output from running the SAS Autoregression procedure with two lags on all samples except the last one. The results of the one-beta, the two-beta and the three-beta hedge for the Eurodollar futures hedge and the T-bill futures hedge are presented in Table 4 thru Table 9.

For the Eurodollar futures hedge, the cross-hedging effectiveness ($R^2$) of the one-beta hedge in Table 4, is in the range of 75\% and 98\%. All the cross-hedge ratios are statistically significantly different from one except the Euro-British pound rate case. The cross-hedging
effectiveness of the two-beta hedge in Table 5 is only slightly better than that of the one-beta hedge but the betas of currency futures in the two-beta hedges are not statistically significantly different from one. The cross-hedging effectiveness of the three-beta hedge in Table 6 is in the range of 84% and 98% and only a little better than that of the two-beta hedge. Further, all the betas of 3-month and 6-month currency futures in the three-beta hedges are not statistically significantly different from one.

For the T-Bill futures hedge, the in-sample cross-hedging effectiveness ($R^2$) of the one-beta hedge in Table 7 is in the range of 62% and 91% which is smaller than that for the Eurodollar futures hedge. All betas are not statistically significantly different from one except the Euro-Japanese yen rate case. The cross-hedging effectiveness ($R^2$) of the two-beta hedge in Table 8 is in the range of 62% and 92% and only a little better than that of the one-beta hedge, and all the betas of the two-beta hedge are not statistically significantly different from one except the Euro-Japanese yen rate case. The cross-hedging effectiveness ($R^2$) of the three-beta hedge in Table 9 is in the range of 66% and 92% and all the betas are not statistically significantly different from one except the Euro-Japanese yen rate case. By comparing all optimal hedging results for the T-bill futures hedge we find that the in-sample cross-hedging effectiveness ($R^2$) is improved only a little when the number of betas gets larger.
In sum, for both the Eurodollar futures hedge and the T-bill futures hedge, when the number of betas increases from one to three, the in-sample cross-hedging effectiveness is improved only a little but betas become less statistically significantly different from one for all cases. It seems that the correlation between the return of Eurodollar futures (or T-bill futures) and the total return of two currency futures, or the correlation among the return of Eurodollar futures (or T-bill futures), the return of 3-month currency futures and the return of 6-month currency futures causes the multicollinearity problem because the betas become less significantly different from one. Further, by comparing the in-sample cross-hedging effectiveness ($R^2$) in Tables 4-9, we find that the Eurodollar futures hedging portfolio can be used to cross-hedge Eurocurrency interest rate risk better than the T-Bill futures hedging portfolio because the return of the Eurodollar futures portfolio is obviously more highly correlated with Eurocurrency interest rate risk than that of the T-Bill futures portfolio.

(2). The Out-Of-Sample Cross-Hedging Effectiveness

In this dissertation we divide the whole sample period into two halves and the second half of the sample period is used as the "out-of-sample" period. For the out-of-sample naive cross-hedging the cross-hedge ratio is always equal to one. But for the out-of-sample optimal cross-hedging the first set of cross-hedge ratios is the set of parameter estimates obtained from running the SAS Autoregression procedure by one, two and three independent variables with two lags on
the first half of the sample period. The first set of estimated cross-hedge ratios is used to cross-hedge the next period's Eurocurrency interest rate risk and the deviation or the hedged interest rate risk is calculated. Then the in-sample is expanded to include the next period and we rerun the SAS Autoregression procedure with two lags again to find the second set of estimated cross-hedge ratios and to calculate another hedged interest rate risk again. The rolling autoregression procedure continues by using SAS MACRO statement till the last run (i.e., there are N-1 observations in the in-sample) whose cross-hedge ratios and correlation coefficients (R²) are shown in Table 4 thru Table 9. Similarly, the estimated cross-hedge ratios from the last run is used to cross-hedge the next period's, i.e., the last period's, Eurocurrency interest rate risk and then the last hedged interest rate risk is computed.

The out-of-sample individual unhedged interest rate risk (\(e^U\)), the individual naive hedged interest rate risk (\(e^N\)) and the individual optimal hedged interest rate risk for the one-beta hedge, the two-beta hedge and the three-beta hedge (\(e^0, e^2, e^3\) respectively) are plotted in Figure 2 thru Figure 17. In those sixteen Figures "U" stands for the individual unhedged interest rate risk (\(e^U\)). "N" stands for the individual naive hedged interest rate risk (\(e^N\)). "0", "2" and "3" stand for the individual optimal hedged interest rate risk of the optimal (or the one-beta) hedge (\(e^0\)), the two-beta hedge (\(e^2\)) and the three-beta hedge (\(e^3\)) respectively.
When we have a glance at Figures 2-17 we find that in general the individual points of the optimally hedged interest rate risk are randomly distributed around zero. Generally, this implies that there is no model misspecification for optimal cross-hedging models and that naive cross-hedging models don't fit well. We also find that it is difficult to distinguish the lines of interest rate risk of optimal hedges, "0", "2" and "3" in these eight figures. This implies that the whole-package (one-beta) optimal hedge works as well as the two-beta hedge and the three-beta hedge. Further, we find that the optimal hedging strategy ("0") has smaller absolute interest rate risk than the naive hedging strategy ("N") for the Eurodollar futures hedges, and the interest rate risk is lower with the naive hedging strategy ("N") than with no hedging ("U"). This implies that the optimal and naive hedging strategies with U.S. financial futures can be used to reduce foreign interest rate risk but the optimal hedging strategy works better than the naive hedging strategy for the Eurodollar futures hedges.

If we compare the distribution in Figures 2-9 to that in Figures 10-17 case by case, obviously we find that the Eurodollar futures hedging portfolio has smaller absolute interest rate risk than the T-bill futures hedging portfolio for the optimal hedging strategy, and for the naive hedging strategy except the Euro-British pound rate case. In other words, the Eurodollar futures hedging portfolio cross-hedges Eurocurrency interest rates better than the T-bill futures hedging portfolio. This also implies that the IRPT holds better in the Euromarket than in T-bill markets.
Finally, the out-of-sample root-mean-squared unhedged interest rate risk, the root-mean-squared naive-hedge interest rate risk, the root-mean-squared optimal-hedge interest rate risk for the one-beta hedge, the two-beta hedge and the three-beta hedge, and the cross-hedging effectiveness \( (CHE_{RMSE}) \) with various cross-hedge ratios are presented in Table 10 and Table 11 for the Eurodollar futures hedge, and in Table 12 and Table 13 for the T-bill futures hedge.

From the out-of-sample cross-hedging effectiveness \( (CHE_{RMSE}) \) for the Eurodollar futures hedge in Table 10 and Table 11 we find that the optimal hedge (whose cross-hedging effectiveness is in the range of 66% and 89%) works better than the naive hedge (whose cross-hedging effectiveness is in the range of 26% and 82%) regardless of the number of betas for all four cases.

For the Euro-British pound rate case, the unhedged interest rate risk is 189.5 basis points and the naive hedged interest rate risk is 62.9 basis points, so the cross-hedging effectiveness is 66.81%. But the one-beta optimal hedged interest rate risk is 63.9 basis points and the cross-hedging effectiveness is 66.30%, which is a little worse than that of the naive hedge. The two-beta optimal hedged interest rate risk is further reduced to 48.3 basis points and the cross-hedging effectiveness jumps to 74.50%, which is much better than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is 48.0 basis points and the cross-hedging effectiveness is 74.67%, which is almost the same as that of the two-beta optimal hedge.
For the Euro-Deutsche mark rate case, the unhedged interest rate risk is 141.3 basis points and the naive hedged interest rate risk is 46.7 basis points, so the cross-hedging effectiveness is 66.98%. But the one-beta optimal hedged interest rate risk is only 27.6 basis points and the cross-hedging effectiveness is 80.44%, which is obviously better than that of the naive hedge. The two-beta optimal hedged interest rate risk is further reduced to 23.1 basis points and the cross-hedging effectiveness raises to 83.68%, which is better than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is 22.8 basis points and the cross-hedging effectiveness is 83.88%, which is almost the same as that of the two-beta optimal hedge.

For the Euro-Japanese yen rate case, the unhedged interest rate risk is 70.3 basis points and the naive hedged interest rate risk is 52.0 basis points, so the cross-hedging effectiveness is 26.01%. But the one-beta optimal hedged interest rate risk is only 24.2 basis points and the cross-hedging effectiveness is 65.61%, which is obviously much better than that of the naive hedge. The two-beta optimal hedged interest rate risk is further reduced to 19.3 basis points and the cross-hedging effectiveness jumps to 72.48%, which is much better than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is 16.5 basis points and the cross-hedging effectiveness is 76.53%, which is slightly better than that of the two-beta optimal hedge.

For the Euro-Swiss franc rate case, the unhedged interest rate risk is 196.0 basis points and the naive hedged interest rate risk is
35.3 basis points, so the cross-hedging effectiveness is 81.99%. But
the one-beta optimal hedged interest rate risk is only 25.9 basis
points and the cross-hedging effectiveness is 86.76%, which is better
than that of the naive hedge. The two-beta optimal hedged interest
rate risk is further reduced to 22.5 basis points and the cross­
hedging effectiveness raises to 88.50%, which is slightly better than
that of the one-beta optimal hedge. However, the three-beta optimal
hedged interest rate risk rises to 23.5 basis points and the cross­
hedging effectiveness declines to 87.99%, which is slightly worse than
that of the two-beta optimal hedge.

Comparing the cross-hedging effectiveness among the foreign
interest rates, we find that the optimal hedging strategy of the
Eurodollar futures hedging portfolio can be used to cross-hedge Euro-
Swiss franc rates and Euro-Deutsche mark rates better than to cross-
hedge Euro-British pound rates and Euro-Japanese yen rates, and that
the Eurodollar futures naive hedge works poorly for the Euro-Japanese
yen rate case. For all cases, the increase of the cross-hedging
effectiveness from the one-beta hedge to the two-beta hedge is higher
than that of the cross-hedging effectiveness from the two-beta hedge
to the three-beta hedge. However, in general the more betas cannot
improve the cross-hedging effectiveness much.

From the out-of-sample naive cross-hedging effectiveness
(CHE_{RMSE}) for the T-bill futures hedge in Table 12 we find that it is
in the range of 17% and 74%. By comparing the out-of-sample cross-
hedging effectiveness of the naive hedge in Table 12 with that of the
optimal hedge, whose cross-hedging effectiveness is in the range of 41% and 74%, in Table 13, the optimal hedge is not better than the naive hedge regardless of the number of betas except the Euro-Japanese yen rate case.

For the Euro-British pound rate case, the unhedged interest rate risk is 189.5 basis points and the naive hedged interest rate risk is 61.3 basis points, so the cross-hedging effectiveness is 67.63%. But the one-beta optimal hedged interest rate risk is 64.3 basis points and the cross-hedging effectiveness is 66.08%, which is a little worse than that of the naive hedge. The two-beta optimal hedged interest rate risk slightly rises to 65.2 basis points and the cross-hedging effectiveness goes down to 65.61%, which is slightly worse than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is 64.7 basis points and the cross-hedging effectiveness is 65.84%, which is almost the same as that of the two-beta optimal hedge.

For the Euro-Deutsche mark rate case, the unhedged interest rate risk is 141.3 basis points and the naive hedged interest rate risk is 57.6 basis points, so the cross-hedging effectiveness is 59.27%. But the one-beta optimal hedged interest rate risk is 57.8 basis points and the cross-hedging effectiveness is 59.08%, which is a little worse than that of the naive hedge. The two-beta optimal hedged interest rate risk is reduced to 54.6 basis points and the cross-hedging effectiveness raises to 61.39%, which is slightly better than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is 54.8 basis points and the cross-hedging
effectiveness is 61.21%, which is slightly worse than that of the two-beta optimal hedge.

For the Euro-Japanese yen rate case, the unhedged interest rate risk is 70.3 basis points and the naive hedged interest rate risk is 58.2 basis points, so the cross-hedging effectiveness is 17.14%. But the one-beta optimal hedged interest rate risk is only 41.5 basis points and the cross-hedging effectiveness is 40.99%, which is obviously much better than that of the naive hedge. The two-beta optimal hedged interest rate risk is reduced to 40.6 basis points and the cross-hedging effectiveness goes up to 42.26%, which is slightly better than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is 37.2 basis points and the cross-hedging effectiveness is 47.07%, which is slightly better than that of the two-beta optimal hedge.

For the Euro-Swiss franc rate case, the unhedged interest rate risk is 196.0 basis points and the naive hedged interest rate risk is 51.8 basis points, so the cross-hedging effectiveness is 73.55%. But the one-beta optimal hedged interest rate risk is 53.8 basis points and the cross-hedging effectiveness is 72.53%, which is a little worse than that of the naive hedge. The two-beta optimal hedged interest rate risk is reduced to 51.3 basis points and the cross-hedging effectiveness rises to 73.81%, which is slightly better than that of the one-beta optimal hedge. However, the three-beta optimal hedged interest rate risk is reduced to 51.1 basis points and the cross-hedging effectiveness goes up to 73.95%, which is almost the same as that of the two-beta optimal hedge.
Comparing the cross-hedging effectiveness among the foreign interest rates, we find that the naive and optimal hedging strategies of the T-bill futures hedging portfolio can be used to cross-hedge Euro-Swiss franc rates, Euro-British pound rates and Euro-Deutsche mark rates better than to cross-hedge Euro-Japanese yen rates, and that the optimal hedging strategy doesn't outperform the naive hedging strategy in three of four cases (except the Euro-Japanese yen rate case). In general, the cross-hedging effectiveness with different number of betas are not much different. Sometimes they get worse for some cases when the number of betas gets larger from one to three.

By comparing the out-of-sample cross-hedging effectiveness (CHE\textsubscript{RMSE}) of the naive and the optimal hedge for the Eurodollar futures hedging portfolio with that for the T-bill futures hedging portfolio, we find that the Eurodollar futures hedging portfolio can cross-hedge Eurocurrency interest rate risk better than the T-Bill futures hedging portfolio for the optimal hedging strategies in all cases and for the naive hedging strategy in three of four cases (except the Euro-British pound rate case). Further, the optimal hedging strategy of both the Eurodollar and T-bill futures hedging portfolios can be used to cross-hedge Euro-Swiss franc rates most effectively and to cross-hedge Euro-Japanese yen rates relatively least effectively.

(3). Overall Results

We summarize all the empirical results in this section as follows:
a. Comparing the in-sample naive cross-hedging effectiveness
\((\text{CHE}_{\text{RMSE}})\) we find that the Eurodollar futures hedging portfolio can
cross-hedge Eurocurrency interest rate risk better than the T-bill
futures hedging portfolio.

b. All the optimal cross-hedge ratios (b's) of the one-beta hedge
and the betas of the Eurodollar futures in the multiple-beta hedges
are statistically significantly different from one for the Eurodollar
futures hedge except the Euro-British pound rate case. In other
words, the betas of multiple-beta hedges become less statistically
significantly different from one than those of the single-beta hedges
owing to the highly correlated independent variables. But all the
optimal hedge ratios are not statistically significantly different
from one for the T-bill futures hedges except the Euro-Japanese yen
rate case.

c. The in-sample cross-hedging effectiveness \((R^2)\) is improved very
little in all cases for the T-bill futures hedge and in three out of
four cases for the Eurodollar futures hedge (the Euro-Japanese yen
rate case is the only exception), when the number of cross-hedge
ratios (b's) gets larger from one to three.

d. The out-of-sample cross hedging effectiveness \((\text{CHE}_{\text{RMSE}})\) shows
that the optimal cross-hedging strategy works better than the naive
cross-hedging strategy for the Eurodollar futures hedge, regardless of
the number of betas. But this is not true for the T-bill futures
hedges except the Euro-Japanese yen rate case. Further, the naive and
optimal hedging strategies can cross-hedge Euro-Swiss franc rates most
effectively and Euro-Japanese yen rates relatively least effectively for both the Eurodollar and T-bill futures hedging portfolios.

e. The out-of-sample cross-hedging effectiveness \( (CHE_{RMSE}) \) shows that the Eurodollar futures hedging portfolio cross-hedges foreign interest rate risk better than the T-bill futures hedging portfolio for both the optimal and naive hedging strategies.

f. The out-of-sample cross-hedging effectiveness \( (CHE_{RMSE}) \) is improved when the number of cross-hedge ratios \( (b's) \) increases from one to two for the Eurodollar futures hedge, but it's not improved from two to three betas for Eurodollar futures hedge, and from one to three for the T-bill futures hedge. In other words, the whole package of futures hedging portfolio (i.e. the one-beta hedge) can work as well as the separate sets of futures hedging portfolio (i.e. the two-beta hedge and the three-beta hedge) without causing the multicollinearity problem.
V. CONCLUSION

In this dissertation we examine the effectiveness of cross-hedging foreign interest rate risk with U.S. financial futures. We use a rolling autoregression procedure to capture the property of time-varying betas (cross-hedge ratios) and use a new test statistic of the out-of-sample cross-hedging effectiveness to compare the performance between the futures hedging portfolios, hedging strategies, and among foreign interest rates. Finally, we get three satisfactory results as follows:

First, U.S. financial futures (short-term interest rate futures and currency futures) can be used for cross-hedging short-term foreign interest rates successfully. This is consistent with Seymour's results, and the evidence of hedging domestic interest rates with interest rate futures and hedging foreign exchange rates with currency futures. Second, the optimal cross-hedging strategies of the Eurodollar futures hedges can cross-hedge foreign interest rate risk better than the naive cross-hedging strategy. This evidence is consistent with Ederington's and Franckle's findings in hedging domestic interest rate risk. Third, the Eurodollar futures hedging portfolio works better than the T-bill futures hedging portfolio. This implies that the Interest Rate Parity Theorem holds better in the Euromarket (external market) than in T-bill markets (internal markets or domestic markets). This implication is consistent with the evidence on the Interest Rate Parity Theorem in the Euromarket.
1. Ederington [1979] pioneers to examine the effectiveness of hedging domestic interest rates with interest rate futures and then Franckle [1980] has comment on it. Many studies followed Ederington’s model and they will be discussed in the literature later in this dissertation. There are only some studies on the hedging effectiveness of foreign currency futures. Dale [1981] and Hill and Schneewels [1981a, 1981b and 1982], using Ederington’s model, examine the hedging effectiveness of currency futures markets and find that foreign currency futures are effective to reduce the foreign exchange risk exposure. Chang and Shanker [1986], using Howard and D’Antonio’s [1984] risk-return approach, compare the hedging effectiveness of two instruments, currency futures contracts and currency options contracts, in hedging exchange rate risk and find that the option synthetic futures contract performs the hedging function less effectively than the futures contract. Eaker and Grant [1987], using Anderson and Danthine’s [1981] cross-hedging model, provide positively empirical evidence on the cross-hedging effectiveness with current futures to reduce foreign exchange risk.

2. Eaker and Grant [1987] point out that the stability of the true hedge ratio ($\beta$) over time is the crucial factor determining the measured cross-hedging effectiveness. There are many ways to solve the time-varying $\beta$ problem. Grammatikos and Saunders [1983] use three different econometric approaches to examine the question of the hedge ratio stability for five foreign currency futures contracts. Those three approaches are: the overlapping (moving or rolling) regression procedure, Quandt’s switching regression analysis and Theil’s random coefficients model. Park [1986] uses nonlinear estimation procedure to estimate the optimal hedge ratio for GNMA futures. Cecchetti, Cumby and Figlewski [1987] use Engle’s [1982] model of autoregressive conditional heteroskedasticity (ARCH) to find the optimal hedge ratio for Treasury bond futures. Many studies have used the rolling regression procedure to capture the property of time-varying $\beta$s for evaluating the out-of-sample forecasting performance. Meese and Rogoff [1983a, 1983b and 1988] and Chiang [1988] use the rolling regression procedure to capture the time-varying property of exchange rate behavior. Seymour [1985] uses the rolling regression procedure to get the time-varying hedge-ratios for interest rate futures and currency futures. Somanath [1986] uses the rolling regression procedure with lagged adjustment to capture time-varying $\beta$s of exchange rate models. In this dissertation we use the rolling autoregression procedure to deal with the time-varying cross-hedge ratios ($\beta$s) for U.S. financial futures to compare the out-of-sample cross-hedging effectiveness.

3. Traditionally when we mention about the "optimal hedging " we always imply that the hedging is to minimize the risk (or variance) without any constraint about return. But Howard and D’Antonio [1984, 1986 and 1987] develop and examine the risk-return approach, which
maximizes the ratio of the expected portfolio return on the standard deviation of the portfolio return, to find the optimal hedge ratio. Cecchetti, Cumby and Figlewski [1987] develop a log-utility maximization model with time-variation property to estimate the optimal hedge ratios. In this dissertation the optimal hedging and the minimum-variance hedging have the same meaning.

4. The accurate computation is as the form:

\[ t_{i,t+1}^{\text{FEC}} = \left[ 100 - F_{i}(t,1) \right] - \left[ \left( F_{i}^{C}(t,2) - F_{i}^{C}(t,1) \right) / F_{i}^{C}(t,1) \right] \times 100 \times \frac{\left[ 360 / \text{number of days} \right]}{100} \]

In order to simplify the calculation we use the approximation form in this dissertation.


6. The Durbin-Watson statistics in Table 14 are not close to 2.0 in most of cases. Thus we decide to run autoregression models to avoid the econometric problem of autocorrelation. Eaker and Grant [1987] regrress the first differences of spot prices on the first differences of futures prices to avoid the potential problem of autocorrelation.

7. The correlation coefficients between the return of interest rate futures and the return of currency futures, and between the return of 3-month currency futures and the return of 6-month currency futures in Table 15 are statistically significantly different from zero. In other words, these independent variable are highly correlated.

8. The correlation coefficients between the return of the Eurodollar futures portfolio and Eurocurrency interest rate risk are much higher than those between the return of the T-Bill futures portfolio and Eurocurrency interest rate risk in Table 16.
Table 1  Observations of Quarterly Futures Prices and Euro-Rates

<table>
<thead>
<tr>
<th>Futures Prices&lt;sup&gt;a&lt;/sup&gt; and Euro-Rates&lt;sup&gt;b&lt;/sup&gt;</th>
<th>The Period of Observations</th>
<th>The number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-bill futures</td>
<td>June 1, 1976 -- December 1, 1987</td>
<td>47</td>
</tr>
<tr>
<td>Eurodollar futures</td>
<td>June 1, 1982 -- December 1, 1987</td>
<td>23</td>
</tr>
<tr>
<td>British pound futures</td>
<td>June 1, 1976 -- December 1, 1987</td>
<td>47</td>
</tr>
<tr>
<td>Deutsche mark futures</td>
<td>December 1, 1976 -- December 1, 1987</td>
<td>45</td>
</tr>
<tr>
<td>Japanese yen futures</td>
<td>June 1, 1977 -- December 1, 1987</td>
<td>43</td>
</tr>
<tr>
<td>Swiss franc futures</td>
<td>June 1, 1976 -- December 1, 1987</td>
<td>47</td>
</tr>
<tr>
<td>Eurodollar rates</td>
<td>March 1, 1976 -- December 1, 1987</td>
<td>48</td>
</tr>
<tr>
<td>Euro-British pound rates</td>
<td>March 1, 1976 -- December 1, 1987</td>
<td>48</td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>March 1, 1976 -- December 1, 1987</td>
<td>48</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>September 1, 1978 -- December 1, 1987</td>
<td>38</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>March 1, 1976 -- December 1, 1987</td>
<td>48</td>
</tr>
</tbody>
</table>

<sup>a</sup> Quarterly futures prices data of International Monetary Market, Chicago Mercantile Exchange (in Chicago) are collected from the Wall Street Journal.

<sup>b</sup> Quarterly Euro-rates data in London are collected from the Financial Times.
Table 2: The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Naive Hedge

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>Root Mean Squared Errors$^a$</th>
<th>Mean Absolute Errors$^b$</th>
<th>Mean Errors$^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e^U$</td>
<td>$e^N$</td>
<td>CHE</td>
</tr>
<tr>
<td>Euro-British pound rates</td>
<td>162.9</td>
<td>53.5</td>
<td>67.12</td>
</tr>
<tr>
<td></td>
<td>(49.2)</td>
<td>(12.2)</td>
<td></td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>108.0</td>
<td>36.8</td>
<td>65.95</td>
</tr>
<tr>
<td></td>
<td>(38.4)</td>
<td>(10.2)</td>
<td></td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>64.1</td>
<td>52.1</td>
<td>18.75</td>
</tr>
<tr>
<td></td>
<td>(19.1)</td>
<td>(15.3)</td>
<td></td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>146.7</td>
<td>31.6</td>
<td>78.49</td>
</tr>
<tr>
<td></td>
<td>(52.7)</td>
<td>(7.9)</td>
<td></td>
</tr>
</tbody>
</table>

a. All the unhedged interest rate risk ($e^U$) and the naive hedged interest rate risk ($e^N$) are stated in basis points, but the cross hedging effectiveness (CHE) is stated in percentage (%).

b. The mean absolute error for unhedged return = $\frac{\sum_{t=1}^{N} e^U_{t}}{N}$.

The mean absolute error for naive hedged return = $\frac{\sum_{t=1}^{N} e^N_{t}}{N}$.

c. The mean error for unhedged return = $\frac{\sum_{t=1}^{N} e^U_{t,t+1}}{N}$.

The mean error for naive hedged return = $\frac{\sum_{t=1}^{N} e^N_{t,t+1}}{N}$.

d. All the values in parentheses are standard errors.
Table 3  The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures Naive Hedge

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>Root Mean Squared Errors(^a)</th>
<th>Mean Absolute Errors(^b)</th>
<th>Mean Errors(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(e^U)</td>
<td>(e^N)</td>
<td>CHE</td>
</tr>
<tr>
<td>Euro-British pound rates</td>
<td>162.9</td>
<td>60.9</td>
<td>62.62</td>
</tr>
<tr>
<td></td>
<td>(49.2)</td>
<td>(14.5)</td>
<td></td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>108.0</td>
<td>48.3</td>
<td>55.26</td>
</tr>
<tr>
<td></td>
<td>(38.4)</td>
<td>(12.2)</td>
<td></td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>64.1</td>
<td>55.5</td>
<td>13.36</td>
</tr>
<tr>
<td></td>
<td>(19.1)</td>
<td>(14.8)</td>
<td></td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>146.7</td>
<td>45.2</td>
<td>69.17</td>
</tr>
<tr>
<td></td>
<td>(52.7)</td>
<td>(10.9)</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) All the unhedged interest rate risk \((e^U)\) and the naive hedged interest rate risk \((e^N)\) are stated in basis points, but the cross-hedging effectiveness \((\text{CHE})\) is stated in percentage (%).  
\(^b\) The mean absolute error for unhedged return = \(E_{t=1}^{N} Abs(e^U_{t+1})/N\).  
The mean absolute error for naive hedged return = \(E_{t=1}^{N} Abs(e^N_{t+1})/N\).  
\(^c\) The mean error for unhedged return = \(E_{t=1}^{N} e^U_{t+1}/N\).  
The mean error for naive hedged return = \(E_{t=1}^{N} e^N_{t+1}/N\).  
\(^d\) All the values in parentheses are standard errors.
Table 4 The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures One-Beta Hedge

\[ e_{i,t+1} = \alpha + \beta_{i,t+1}(r_{i,t+1}^{EDF} + 4r_{i,t+1}^{CF3} + 4r_{i,t+1}^{CF6}) + u_{i,t+1}, \]
\[ t = 1, \ldots, N. \]

where 
- \( r_{i,t+1}^{EDF} \) is the annual return of the quarterly Eurodollar futures contract by buying it at \( t \) and selling it at \( t+1 \),
- \( r_{i,t+1}^{CF3} \) is the quarterly return of the 3-month \( i \)-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \),
- \( r_{i,t+1}^{CF6} \) is the quarterly return of the 6-month \( i \)-th currency futures contract by buying it at \( t \) and selling it at \( t+1 \),
- \( e_{i,t+1}^{U} \) is the unhedged interest rate risk for the \( i \)-th Eurocurrency deposit,
- \( \alpha \) is the intercept of regression,
- \( \beta_{i,t+1} \) is the slope of regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),
- \( u_{i,t+1} \) is the error term of the regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),
- \( R^2 \) is the correlation coefficient of regression.

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( b_{i,N-1} )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>0.999 ( ^\ast )</td>
<td>0.972</td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>0.817 ( ^\ast )</td>
<td>0.951</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>0.695 ( ^\ast )</td>
<td>0.751</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>0.910 ( ^\ast )</td>
<td>0.979</td>
</tr>
</tbody>
</table>

All the values are from the SAS AUTOREG procedure with two lags on all samples except the last one.

a. All the values in parentheses are standard errors.

* means that the value is statistically significantly different from one at the 5% confidence level.
Table 5  The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Two-Beta Hedge

\[ e_{i,t+1} = a + \beta_{i,t+1}^{EDF} r_{i,t+1}^{EDF} + \beta_{i,t+1}^{CF} r_{i,t+1}^{CF} + \beta_{i,t+1}^{EUF} r_{i,t+1}^{EUF} + \beta_{i,t+1}^{CF6} r_{i,t+1}^{CF6} + u_{i,t+1}, \]

where \( r_{i,t+1}^{EDF} \) = the annual return of the quarterly Eurodollar futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( r_{i,t+1}^{CF3} \) = the quarterly return of the 3-month \( i \)-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \),

\( r_{i,t+1}^{CF6} \) = the quarterly return of the 6-month \( i \)-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \),

\( e_{i,t+1}^{U} \) = the unhedged interest rate risk for the \( i \)-th Eurocurrency deposit,

\( a \) = the intercept of regression,

\( \beta_{i,t+1}^{EDF}, \beta_{i,t+1}^{CF} \) = the slopes of regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),

\( u_{i,t+1} \) = the error term of the regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),

\( R^2 \) = the correlation coefficient of regression.

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( b_{i,N-1}^{EDF} )</th>
<th>( b_{i,N-1}^{CF} )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>0.934 (0.046)(^a)</td>
<td>1.033 (0.043)</td>
<td>0.975 N = 21</td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>0.813* (0.030)</td>
<td>0.929 (0.045)</td>
<td>0.969 N = 21</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>0.710* (0.087)</td>
<td>0.845 (0.096)</td>
<td>0.817 N = 21</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>0.885* (0.033)</td>
<td>0.968 (0.044)</td>
<td>0.982 N = 21</td>
</tr>
</tbody>
</table>

All the values are from the SAS AUTOREG procedure with two lags on all samples except the last one.

\(^a\) All the values in parentheses are standard errors.

* means that the value is statistically significantly different from one at the 5% confidence level.
Table 6 The In-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Three-Beta Hedge

\[ U_{i,t+1} = \alpha + \beta_{i,t+1}^{EDF} r_{t+1}^{EDF} + \beta_{i,t+1}^{CF3} r_{i,t+1}^{CF3} + \beta_{i,t+1}^{CF6} r_{i,t+1}^{CF6} + u_{i,t+1}, \ t = 1, \ldots, N. \]

where \( r_{t+1}^{EDF} \) = the annual return of the quarterly Eurodollar futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( r_{i,t+1}^{CF3} \) = the quarterly return of the 3-month \( i \)-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \),

\( r_{i,t+1}^{CF6} \) = the quarterly return of the 6-month \( i \)-th currency futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( U_{i,t+1} \) = the unhedged interest rate risk for the \( i \)-th Eurocurrency deposit,

\( \alpha \) = the intercept of regression,

\( \beta_{i,t+1}^{EDF}, \beta_{i,t+1}^{CF3}, \beta_{i,t+1}^{CF6} \) = the slopes of regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),

\( u_{i,t+1} \) = the error term of the regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),

\( R^2 \) = the correlation coefficient of regression.

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( b_{i,N-1}^{EDF} )</th>
<th>( b_{i,N-1}^{CF3} )</th>
<th>( b_{i,N-1}^{CF6} )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>0.936</td>
<td>1.021</td>
<td>1.022</td>
<td>0.976</td>
</tr>
<tr>
<td></td>
<td>(0.047)(^a)</td>
<td>(0.046)</td>
<td>(0.045)</td>
<td>N = 21</td>
</tr>
<tr>
<td>Euro-Deutsche Mark rates</td>
<td>0.806*</td>
<td>0.930</td>
<td>0.929</td>
<td>0.973</td>
</tr>
<tr>
<td></td>
<td>(0.028)</td>
<td>(0.043)</td>
<td>(0.043)</td>
<td>N = 21</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>0.684*</td>
<td>0.819</td>
<td>0.815</td>
<td>0.844</td>
</tr>
<tr>
<td></td>
<td>(0.085)</td>
<td>(0.095)</td>
<td>(0.096)</td>
<td>N = 21</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>0.881*</td>
<td>0.966</td>
<td>0.965</td>
<td>0.983</td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.044)</td>
<td>(0.044)</td>
<td>N = 21</td>
</tr>
</tbody>
</table>

All the values are from the SAS AUTOREG procedure with two lags on all samples except the last one.

\( a \). All the values in parentheses are standard errors.

* means that the value is statistically significantly different from one at the 5% confidence level.
Table 7  The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures One-Beta Hedge

\[ e_{i,t+1} = \alpha + \beta_{i,t+1} (r_{t+1}^{\text{BF}} + 4r_{i,t+1}^{\text{CF3}} + 4r_{i,t+1}^{\text{CF6}}) + u_{i,t+1}, \]

where \( r_{t+1}^{\text{BF}} \) = the annual return of the quarterly T-bill futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( r_{i,t+1}^{\text{CF3}} \) = the quarterly return of the 3-month i-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \),

\( r_{i,t+1}^{\text{CF6}} \) = the quarterly return of the 6-month i-th currency futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( e_{i,t+1} \) = the unhedged interest rate risk for the i-th Eurocurrency deposit,

\( \alpha \) = the intercept of regression,

\( \beta_{i,t+1} \) = the slope of regression for the i-th Eurocurrency deposit at \( t+1 \),

\( u_{i,t+1} \) = the error term of the regression for the i-th Eurocurrency deposit at \( t+1 \),

\( R^2 \) = the correlation coefficient of regression.

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( b_{i,N-1} )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>0.943</td>
<td>0.907</td>
</tr>
<tr>
<td></td>
<td>(0.074)(^a)</td>
<td>( N = 21 )</td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>0.894</td>
<td>0.792</td>
</tr>
<tr>
<td></td>
<td>(0.105)</td>
<td>( N = 21 )</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>0.574*</td>
<td>0.622</td>
</tr>
<tr>
<td></td>
<td>(0.116)</td>
<td>( N = 21 )</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>0.970</td>
<td>0.903</td>
</tr>
<tr>
<td></td>
<td>(0.077)</td>
<td>( N = 21 )</td>
</tr>
</tbody>
</table>

All the values are from the SAS AUTOREG procedure with two lags on all samples except the last one.

\(^a\) All the values in parentheses are standard errors.

* means that the value is statistically significantly different from one at the 5% confidence level.
Table 8  The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures Two-Beta Hedge

\[ e_{i,t+1} = \alpha + \beta_{TBF,i,t+1}(r_{TBF}^{t+1}) + \beta_{CF,i,t+1}(4r_{CF3}^{t+1} + 4r_{CF6}^{t+1}) + u_{i,t+1}, \]
\[ t = 1, \ldots, N. \]

where \( r_{TBF}^{t+1} \) - the annual return of the quarterly T-bill futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( r_{CF3}^{i,t+1} \) - the quarterly return of the 3-month \( i \)-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \),

\( r_{CF6}^{i,t+1} \) - the quarterly return of the 6-month \( i \)-th currency futures contract by buying it at \( t \) and selling it at \( t+1 \),

\( e_{i,t+1} \) - the unhedged interest rate risk for the \( i \)-th Eurocurrency deposit,

\( \alpha \) - the intercept of regression,

\( \beta_{TBF,i,t+1}, \beta_{CF,i,t+1} \) - the slopes of regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),

\( u_{i,t+1} \) - the error term of the regression for the \( i \)-th Eurocurrency deposit at \( t+1 \),

\( R^2 \) - the correlation coefficient of regression.

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( b_{TBF}^{i,N-1} )</th>
<th>( b_{CF}^{i,N-1} )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>1.017</td>
<td>0.918</td>
<td>0.912</td>
</tr>
<tr>
<td>(0.101)*</td>
<td>(0.078)</td>
<td>( N = 21 )</td>
<td></td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>0.908</td>
<td>0.851</td>
<td>0.796</td>
</tr>
<tr>
<td>(0.109)</td>
<td>(0.131)</td>
<td>( N = 21 )</td>
<td></td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>0.600*</td>
<td>0.556*</td>
<td>0.621</td>
</tr>
<tr>
<td>(0.136)</td>
<td>(0.126)</td>
<td>( N = 21 )</td>
<td></td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>1.030</td>
<td>0.886</td>
<td>0.916</td>
</tr>
<tr>
<td>(0.078)</td>
<td>(0.086)</td>
<td>( N = 21 )</td>
<td></td>
</tr>
</tbody>
</table>

All the values are from the SAS AUTOREG procedure with two lags on all samples except the last one.

* means that the value is statistically significantly different from one at the 5% confidence level.

a. All the values in parentheses are standard errors.
Table 9  The In-Sample Cross-Hedging Effectiveness for the T-Bill Futures Three-Beta Hedge

\[
e_{i,t+1} = \alpha + \beta_{TBF} r_{TBF,t+1} + \beta_{CF3} r_{CF3,t+1} + \beta_{CF6} r_{CF6,t+1} + u_{i,t+1}, \quad t = 1, \ldots, N.
\]

where \( r_{TBF,t+1} \) is the annual return of the quarterly T-bill futures contract by buying at \( t \) and selling it at \( t+1 \), \( r_{CF3,t+1} \) is the quarterly return of the 3-month \( i \)-th currency futures contract by selling it at \( t \) and buying it at \( t+1 \), \( r_{CF6,t+1} \) is the quarterly return of the 6-month \( i \)-th currency futures contract by buying it at \( t \) and selling it at \( t+1 \), \( e_{i,t+1} \) is the unhedged interest rate risk for the \( i \)-th Eurocurrency deposit, \( \alpha \) is the intercept of regression, \( \beta_{TBF} \), \( \beta_{CF3} \), \( \beta_{CF6} \) are the slopes of regression for the \( i \)-th Eurocurrency deposit at \( t+1 \), \( u_{i,t+1} \) is the error term of the regression for the \( i \)-th Eurocurrency deposit at \( t+1 \), \( R^2 \) is the correlation coefficient of regression.

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( b_{TBF,i,N-1} )</th>
<th>( b_{CF3,i,N-1} )</th>
<th>( b_{CF6,i,N-1} )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>1.024</td>
<td>0.907</td>
<td>0.909</td>
<td>0.912</td>
</tr>
<tr>
<td></td>
<td>(0.105)\textsuperscript{a}</td>
<td>(0.085)</td>
<td>(0.083)</td>
<td>( N = 21 )</td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>0.906</td>
<td>0.856</td>
<td>0.854</td>
<td>0.800</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.133)</td>
<td>(0.133)</td>
<td>( N = 21 )</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>0.575\textsuperscript{*}</td>
<td>0.535\textsuperscript{*}</td>
<td>0.530\textsuperscript{*}</td>
<td>0.659</td>
</tr>
<tr>
<td></td>
<td>(0.135)</td>
<td>(0.126)</td>
<td>(0.127)</td>
<td>( N = 21 )</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>1.022</td>
<td>0.885</td>
<td>0.884</td>
<td>0.918</td>
</tr>
<tr>
<td></td>
<td>(0.081)</td>
<td>(0.087)</td>
<td>(0.087)</td>
<td>( N = 21 )</td>
</tr>
</tbody>
</table>

All the values are from the SAS AUTOREG procedure with two lags on all samples except the last one.

\textsuperscript{a} All the values in parentheses are standard errors.

\* means that the value is statistically significantly different from one at the 5% confidence level.
Table 10  The Out-of-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Naive Hedge

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>Unhedged e^U^a</th>
<th>Naive Hedged e^N^a</th>
<th>CHE^b_{RMSE}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td>189.5</td>
<td>62.9</td>
<td>66.81</td>
</tr>
<tr>
<td></td>
<td>(81.8)c</td>
<td>(19.9)</td>
<td></td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td>141.3</td>
<td>46.7</td>
<td>66.98</td>
</tr>
<tr>
<td></td>
<td>(64.1)</td>
<td>(16.4)</td>
<td></td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td>70.3</td>
<td>52.0</td>
<td>26.01</td>
</tr>
<tr>
<td></td>
<td>(26.2)</td>
<td>(19.3)</td>
<td></td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td>196.0</td>
<td>35.3</td>
<td>81.99</td>
</tr>
<tr>
<td></td>
<td>(87.6)</td>
<td>(12.7)</td>
<td></td>
</tr>
</tbody>
</table>

a. All the unhedged interest rate risk (e^U^) and the naive hedged interest rate risk (e^N^) are stated in basis points.
b. All the cross-hedging effectiveness (CHE^b_{RMSE}) is stated in percentage (%).
c. The values in parentheses are standard errors.
Table 11 The Out-of-Sample Cross-Hedging Effectiveness for the Eurodollar Futures Optimal Hedge

<table>
<thead>
<tr>
<th>Foreign Interest</th>
<th>Unhedged</th>
<th>Optimal Hedged</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One-beta</td>
<td>Two-beta</td>
</tr>
<tr>
<td>Rates</td>
<td></td>
<td>Three-beta</td>
</tr>
<tr>
<td>Euro-British</td>
<td>189.5</td>
<td>48.3</td>
</tr>
<tr>
<td>pound rates</td>
<td>63.9</td>
<td>74.50</td>
</tr>
<tr>
<td></td>
<td>(63.9)</td>
<td>(16.8)</td>
</tr>
<tr>
<td></td>
<td>66.30</td>
<td>(16.8)</td>
</tr>
<tr>
<td>Euro-Deutsche</td>
<td>141.3</td>
<td>23.1</td>
</tr>
<tr>
<td>mark rates</td>
<td>27.6</td>
<td>83.68</td>
</tr>
<tr>
<td></td>
<td>(64.1)</td>
<td>(8.0)</td>
</tr>
<tr>
<td></td>
<td>80.44</td>
<td>(7.9)</td>
</tr>
<tr>
<td>Euro-Japanese</td>
<td>70.3</td>
<td>19.3</td>
</tr>
<tr>
<td>yen rates</td>
<td>24.2</td>
<td>72.48</td>
</tr>
<tr>
<td></td>
<td>(26.2)</td>
<td>(7.5)</td>
</tr>
<tr>
<td></td>
<td>65.61</td>
<td>(5.2)</td>
</tr>
<tr>
<td>Euro-Swiss</td>
<td>196.0</td>
<td>22.5</td>
</tr>
<tr>
<td>franc rates</td>
<td>25.9</td>
<td>88.50</td>
</tr>
<tr>
<td></td>
<td>(87.6)</td>
<td>(8.1)</td>
</tr>
<tr>
<td></td>
<td>86.76</td>
<td>(8.3)</td>
</tr>
<tr>
<td></td>
<td>(8.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8.1)</td>
<td></td>
</tr>
</tbody>
</table>

a. All the unhedged interest rate risk ($e^U$) and the optimal hedged interest rate risk ($e^O$), the two-beta optimal hedged interest rate risk ($e^2$) and the three-beta optimal hedged interest rate risk ($e^3$) are stated in basis points.

b. All the root-mean-squared-error cross-hedging effectiveness (CHE) is stated in percentage (%).

c. The values in parentheses are standard errors.
Table 12  The Out-of-Sample Cross-Hedging Effectiveness for the T-Bill Futures Naive Hedge

<table>
<thead>
<tr>
<th>Foreign Interest</th>
<th>Unhedged $e^U$</th>
<th>Naive Hedged $e^N$</th>
<th>CHE$_{RMSE}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest Rates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro-British</td>
<td>189.5</td>
<td>61.3</td>
<td>67.63</td>
</tr>
<tr>
<td>pound rates</td>
<td>(81.8)$^c$</td>
<td>(20.9)</td>
<td></td>
</tr>
<tr>
<td>Euro-Deutsche</td>
<td>141.3</td>
<td>57.6</td>
<td>59.27</td>
</tr>
<tr>
<td>mark rates</td>
<td>(64.1)</td>
<td>(19.2)</td>
<td></td>
</tr>
<tr>
<td>Euro-Japanese</td>
<td>70.3</td>
<td>58.2</td>
<td>17.14</td>
</tr>
<tr>
<td>yen rates</td>
<td>(26.2)</td>
<td>(22.0)</td>
<td></td>
</tr>
<tr>
<td>Euro-Swiss</td>
<td>196.0</td>
<td>51.8</td>
<td>73.55</td>
</tr>
<tr>
<td>franc rates</td>
<td>(87.6)</td>
<td>(16.6)</td>
<td></td>
</tr>
</tbody>
</table>

a. All the unhedged interest rate risk ($e^U$) and the naive hedged interest rate risk ($e^N$) are stated in basis points.
b. All the cross-hedging effectiveness (CHE$_{RMSE}$) is stated in percentage (%).
c. The values in parentheses are standard errors.
Table 13 The Out-of-Sample Cross-Hedging Effectiveness for the T-Bill Futures Optimal Hedge

<table>
<thead>
<tr>
<th>Foreign Interest</th>
<th>Unhedged</th>
<th>One-beta</th>
<th>Two-beta</th>
<th>Three-beta</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e^u$</td>
<td>$e^0$</td>
<td>CHE$^b$</td>
<td>$e^2$</td>
</tr>
<tr>
<td>Euro-British</td>
<td>189.5</td>
<td>64.3</td>
<td>66.08</td>
<td>65.2</td>
</tr>
<tr>
<td>pound rates</td>
<td>(81.8)$^c$</td>
<td>(23.1)</td>
<td>(24.3)</td>
<td>(23.5)</td>
</tr>
<tr>
<td>Euro-Deutsche</td>
<td>141.3</td>
<td>57.8</td>
<td>59.08</td>
<td>54.6</td>
</tr>
<tr>
<td>mark rates</td>
<td>(64.1)</td>
<td>(17.4)</td>
<td>(17.0)</td>
<td>(16.9)</td>
</tr>
<tr>
<td>Euro-Japanese</td>
<td>70.3</td>
<td>41.5</td>
<td>40.99</td>
<td>40.6</td>
</tr>
<tr>
<td>yen rates</td>
<td>(26.2)</td>
<td>(17.0)</td>
<td>(16.1)</td>
<td>(14.2)</td>
</tr>
<tr>
<td>Euro-Swiss</td>
<td>196.0</td>
<td>53.8</td>
<td>72.53</td>
<td>51.3</td>
</tr>
<tr>
<td>franc rates</td>
<td>(67.6)</td>
<td>(16.9)</td>
<td>(16.2)</td>
<td>(17.9)</td>
</tr>
</tbody>
</table>

a. All the unhedged interest rate risk ($e^u$) and the optimal hedged interest rate risk ($e^0$), the two-beta optimal hedged interest rate risk ($e^2$) and the three-beta optimal hedged interest rate risk ($e^3$) are stated in basis points.
b. All the root-mean-squared-error cross-hedging effectiveness (CHE) is stated in percentage (%).
c. The values in parentheses are standard errors.
Table 14  D-W Statistics\textsuperscript{a}

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>The One-beta Hedge</th>
<th>The Two-beta Hedge</th>
<th>The Three-beta Hedge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro-British pound rates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>1.2525</td>
<td>2.0652</td>
<td>2.0079</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>2.2943</td>
<td>2.1067</td>
<td>1.9835</td>
</tr>
<tr>
<td>Euro-Deutsche mark rates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>2.2135</td>
<td>2.5822</td>
<td>2.6304</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>2.0543</td>
<td>2.0520</td>
<td>2.0923</td>
</tr>
<tr>
<td>Euro-Japanese yen rates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>1.5124</td>
<td>1.6763</td>
<td>1.7576</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>1.4604</td>
<td>1.4366</td>
<td>1.4727</td>
</tr>
<tr>
<td>Euro-Swiss franc rates</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>1.5144</td>
<td>1.9602</td>
<td>1.9816</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>2.1242</td>
<td>2.1430</td>
<td>2.1520</td>
</tr>
</tbody>
</table>

\textsuperscript{a} D-W statistics are from the OLS regression procedure on all samples except the last one.
Table 15  Correlation Coefficients\(^a\)
Among Futures Returns

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>CORR (<em>{CF}^{(r</em>{i}^{CF}, r_{IRF})})</th>
<th>CORR (<em>{CF3}^{(r</em>{i}^{CF3}, r_{IRF})})</th>
<th>CORR (<em>{CF6}^{(r</em>{i}^{CF6}, r_{IRF})})</th>
<th>CORR (<em>{CF3}^{(r</em>{i}^{CF3}, r_{i}^{CF6})})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Euro-British pound rates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>-0.5049 (0.0196)(^b)</td>
<td>0.0966 (0.6771)</td>
<td>-0.1212 (0.6006)</td>
<td>-0.9988 (0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>-0.4179 (0.0594)</td>
<td>0.0834 (0.7192)</td>
<td>-0.1038 (0.6543)</td>
<td>-0.9988 (0.0001)</td>
</tr>
<tr>
<td><strong>Euro-Deutsche mark rates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>-0.6627 (0.0011)</td>
<td>0.0554 (0.8113)</td>
<td>-0.078 (0.7276)</td>
<td>-0.9992 (0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>-0.6669 (0.0010)</td>
<td>0.0497 (0.8306)</td>
<td>-0.0753 (0.7458)</td>
<td>-0.9993 (0.0001)</td>
</tr>
<tr>
<td><strong>Euro-Japanese yen rates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>-0.8648 (0.0001)</td>
<td>0.1022 (0.6594)</td>
<td>-0.1454 (0.5294)</td>
<td>-0.9988 (0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>-0.8100 (0.0001)</td>
<td>0.1034 (0.6555)</td>
<td>-0.1440 (0.5336)</td>
<td>-0.9988 (0.0001)</td>
</tr>
<tr>
<td><strong>Euro-Swiss franc rates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>-0.4857 (0.0256)</td>
<td>0.0161 (0.9449)</td>
<td>-0.0354 (0.8790)</td>
<td>-0.9992 (0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>-0.4547 (0.0384)</td>
<td>0.0168 (0.9424)</td>
<td>-0.0349 (0.8807)</td>
<td>-0.9992 (0.0001)</td>
</tr>
</tbody>
</table>

\(^a\) The correlation coefficient \(\text{CORR}(r_{i}^{CF}, r_{IRF})\) between the return of \(i\)-th currency futures \(r_{i}^{CF}\) and the return of interest rate futures \(r_{IRF}\), the correlation coefficient \(\text{CORR}(r_{i}^{CF3}, r_{IRF})\) between the return of 3-month \(i\)-th currency futures \(r_{i}^{CF3}\) and the return of
interest rate futures, the correlation coefficient \( \text{CORR}(r_{i,6}^{CF}, r_{i,6}^{IRF}) \) between the return of 6-month \( i \)-th currency futures \( r_{i,6}^{CF} \) and the return of interest rate futures, and the correlation coefficient \( \text{CORR}(r_{i,3}^{CF}, r_{i,6}^{CF}) \) between the return of 3-month \( i \)-th currency futures and the return of 6-month \( i \)-th currency futures are from the SAS AUTOREG procedure with two lags on all samples except the last one. 

b. The values in parentheses are p-values for \( H_0: \rho = 0 \).
### Table 16

<table>
<thead>
<tr>
<th>Foreign Interest Rates</th>
<th>( \text{CORR}(e_{1i}^U, r_{i, \text{IRF}}) )</th>
<th>( \text{CORR}(e_{1i}^U, r_{i, F}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Euro-British pound rates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>0.3726</td>
<td>0.9840</td>
</tr>
<tr>
<td></td>
<td>(0.0962) (^b)</td>
<td>(0.0001) (^b)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>0.4217</td>
<td>0.9503</td>
</tr>
<tr>
<td></td>
<td>(0.0569)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td><strong>Euro-Deutsche mark rates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>0.6128</td>
<td>0.9735</td>
</tr>
<tr>
<td></td>
<td>(0.0031)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>0.5397</td>
<td>0.8881</td>
</tr>
<tr>
<td></td>
<td>(0.0116)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td><strong>Euro-Japanese yen rates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>0.3229</td>
<td>0.8593</td>
</tr>
<tr>
<td></td>
<td>(0.1534)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>0.3355</td>
<td>0.7603</td>
</tr>
<tr>
<td></td>
<td>(0.1371)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td><strong>Euro-Swiss franc rates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Eurodollar futures hedge</td>
<td>0.6337</td>
<td>0.9886</td>
</tr>
<tr>
<td></td>
<td>(0.0020)</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>The T-bill futures hedge</td>
<td>0.6249</td>
<td>0.9473</td>
</tr>
<tr>
<td></td>
<td>(0.0025)</td>
<td>(0.0001)</td>
</tr>
</tbody>
</table>

\(^a\) The correlation coefficient \( \text{CORR}(e_{1i}^U, r_{i, \text{IRF}}) \) between the unhedged interest rate risk for \( i \)-th Eurocurrency deposit \( (e_{1i}^U) \) and the return of interest rate futures \( r_{i, \text{IRF}} \), and the correlation coefficient \( \text{CORR}(e_{1i}^U, r_{i, F}) \) between the unhedged interest rate risk and the total return of financial futures \( r_{i, F} \) are from the SAS AUTOREG procedure with two lags on all samples except the last one.

\(^b\) The values in parentheses are p-values for \( H_0: \rho = 0 \).
Figure 1 The Two-Period Cross-Hedging Scheme for the Borrowing Case
Transactions in the futures hedging portfolio:

<table>
<thead>
<tr>
<th>Take opposite positions in the futures portfolio on June 1, 1987:</th>
<th>Close out positions in the futures hedging portfolio on September 1, 1987:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sell September Eurodollar futures short at 92.17</td>
<td>Buy September Eurodollar futures</td>
</tr>
<tr>
<td>Buy September Swiss franc futures at $0.6644</td>
<td>Sell September Swiss franc futures</td>
</tr>
<tr>
<td>Sell December Swiss franc futures short at $0.6703</td>
<td>Buy December Swiss franc futures</td>
</tr>
</tbody>
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Computations of the Euro-Swiss franc interest rate implied by futures, the realized Euro-Swiss franc interest rate from the naive futures hedging and the interest rate risk with naive futures hedging

The September 1 Euro-Swiss franc interest rate implied by futures on June 1, 1987

\[-\frac{100-92.17}{92.17} - \frac{($0.6703-$0.6644)/$0.6644}{4}\times 100\]

\[-7.83\% - 3.55\%

\[-4.28\%

The return from September Eurodollar futures on September 1, 1987

\[-\frac{-92.17 + 92.67}{92.17}\times 100\]

\[-0.54\%

The return from September Swiss franc futures on September 1, 1987

\[-\frac{($0.6644 - $0.6700)/$0.6644}{4}\times 100\]

\[-0.84\%

The return from December Swiss franc futures on September 1, 1987

\[\frac{-($0.6703 + $0.6762)/$0.6703}{4}\times 100\]

\[0.88\%

The total return of the futures portfolio on September 1, 1987

\[-\frac{0.54\% + 4\times(-0.84\%) + 4\times0.88\%}{3}\]

\[0.23\%

The realized Euro-Swiss franc interest rate from the naive futures hedging on September 1, 1987

\[-3.75\% + 1.0\times0.23\%

\[-3.98\%

Figure 1 continued.
The Euro-Swiss franc interest rate risk without hedging on September 1, 1987

- 4.28% - 3.75%
- 0.53%

The Euro-Swiss franc interest rate risk with naive futures hedging on September 1, 1987

- 4.28% - 3.98%
- 0.30%
or - 0.53% - 1.0*0.23%
- 0.30%

The interest rate risk has reduced from 0.53% to 0.30% when we use the naive futures hedging.

Figure 1 continued.
Figure 2  The Out-of-Sample Euro-British Pound Interest Rate Risk from Optimal and Naive Eurodollar Futures Hedges
Figure 3 The Out-of-Sample Euro-British Pound Interest Rate Risk from Various Optimal Eurodollar Futures Hedges
U: Unhedged interest rate risk
N: Naive hedged interest rate risk
O: Optimal (One-beta) hedged interest rate risk

Figure 4 The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk from Optimal and Naive Eurodollar Futures Hedges
Figure 5 The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk from Various Optimal Eurodollar Futures Hedges
Figure 6 The Out-of-Sample Euro-Japanese Yen Interest Rate Risk from Optimal and Naive Eurodollar Futures Hedges

U: Unhedged interest rate risk
N: Naive hedged interest rate risk
O: Optimal (One-beta) hedged interest rate risk

Interest Rate Risk (in basis points)

Number of Observations
0: Optimal (One-beta) hedged interest rate risk
2: Two-beta hedged interest rate risk
3: Three-beta hedged interest rate risk

Figure 7 The Out-of-Sample Euro-Japanese Yen Interest Rate Risk from Various Optimal Eurodollar Futures Hedges
Figure 8  The Out-of-Sample Euro-Swiss Franc Interest Rate Risk from Optimal and Naive Eurodollar Futures Hedges
Figure 9 The Out-of-Sample Euro-Swiss Franc Interest Rate Risk from Various Optimal Eurodollor Futures Hedges
Figure 10 The Out-of-Sample Euro-British Pound Interest Rate Risk from Optimal and Naive T-Bill Futures Hedges
Figure 11 The Out-of-Sample Euro-British Pound Interest Rate Risk from Various Optimal T-bill Futures Hedges
Figure 12 The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk from Optimal and Naive T-Bill Futures Hedges
Figure 13 The Out-of-Sample Euro-Deutsche Mark Interest Rate Risk from Various Optimal T-bill Futures Hedges
Interest Rate Risk (in basis points)

U: Unhedged interest rate risk
N: Naive hedged interest rate risk
O: Optimal (One-beta) hedged interest rate risk

Figure 14 The Out-of-Sample Euro-Japanese Yen Interest Rate Risk from Optimal and Naive T-Bill Futures Hedges
Figure 15 The Out-of-Sample Euro-Japanese Yen Interest Rate Risk from Various Optimal T-bill Futures Hedges
Figure 16 The Out-of-Sample Euro-Swiss Franc Interest Rate Risk from Optimal and Naive T-Bill Futures Hedges
Figure 17 The Out-of-Sample Euro-Swiss Franc Interest Rate Risk from Various Optimal T-bill Futures Hedges
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