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Foreign Exchange Volatility Is Priced in Equities

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Abstract

This paper finds that standard asset pricing models fail to explain the significantly negative delta hedging errors that occur as a result of the purchase of options on foreign exchange futures. Foreign exchange volatility does influence stock returns, however. The volatility of the JPY/USD exchange rate predicts the time series of stock returns and is priced in the cross section of stock returns.

Keywords: exchange rate, option, implied volatility, realized volatility, asset pricing.

JEL subject numbers: F31, G15.

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Foreign Exchange Volatility Is Priced in Equities

Research has consistently found that Black-Scholes implied volatility is a conditionally biased predictor of realized volatility across asset markets. That is, risk-neutral implied volatility exceeds realized volatility. The most popular explanation for this robust phenomenon is that volatility risk is priced, which is very plausible for options on stock market indices.[1] Merton's (1973) intertemporal capital asset pricing model (ICAPM) predicts that investors want to hedge their exposure to stock market volatility because increasing volatility indicates lower quality investment opportunities.[2] Moreover, recent authors, e.g., Chen (2003), Guo (2006b), and Ang et al. (2006), have estimated variants of Merton's ICAPM and found that equity volatility risk is significantly priced in the U.S. stock market.

Black-Scholes implied volatility is also biased for non-equity assets, however, including foreign exchange. This suggests that foreign exchange volatility is also priced in options markets. Why might foreign exchange volatility risk be priced in equilibrium? Priced foreign exchange volatility risk might be related to priced foreign exchange level risk, as documented by Dumas and Solnik (1995), De Santis and Gérard (1998), Choi, Hiraki, and Takezawa (1998), and

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[1] A partial list includes Hull and White (1987), Jackwerth and Rubinstein (1996), Heston (1993), Lamoureoux and Lastrapes (1993), Poteshman (2000), Bakshi, Cao, and Chen (2000), Chernov and Ghysels (2000), Buraschi and Jackwerth (2001), Coval and Shumway (2001), Benzoni (2002), Chernov (2007), Jones (2003), Pan (2002), Bakshi and Kapadia (2003), Eraker, Johannes, and Polson (2003), Neely (2004a, 2004b) and Bollerslev and Zhou (2006).

[2] Recent work, e.g., Ghysels, Santa-Clara, and Valkanov (2005) and Guo and Whitelaw (2006), finds a positive risk-return relation in the stock market, as suggested by the CAPM and ICAPM. This indicates that higher volatility can be associated with improved investment opportunities, i.e., higher expected returns. Therefore, the sign of the price of volatility risk is not clear, a priori, although most studies find it to be negative. This paper also finds that foreign exchange volatility carries a negative risk premium, although it is positively related to future stock market returns.

Ng (2004).[3] If the level of foreign exchange is a risk factor, as it is in the international ICAPM, its volatility should forecast stock market returns and thus degrades investment opportunities by raising volatility. Presumably, higher foreign exchange volatility indicates poorer investment opportunities because it makes hedging foreign exchange level risk more difficult (e.g., Coval and Shumway (2001)).[4] Therefore, one would expect that foreign exchange volatility risk would carry a negative premium.

This research is related to Bakshi and Kapadia (2003, hereafter BK) and Low and Zhang (2005, hereafter LZ), who characterize delta hedging errors in equity and foreign exchange markets, respectively. BK concentrated on showing that the price of volatility risk—as opposed to jump risk—is the source of S&P 500 hedging returns. LZ likewise considered the source of delta hedging profits in foreign exchange markets, as well as how the volatility term structure influenced the risk premium.

We also characterize delta hedging profits, but our motivation and methods differ fundamentally from BK and LZ. The negative premium on foreign exchange volatility should affect other asset markets, including equity markets, as pointed out by Detemple and Selden (1991), Coval and Shumway (2001), and Vanden (2004). We test this idea in three ways. First, we investigate whether standard asset pricing models (APMs) explain the delta hedging errors, which mainly reflect volatility risk, as argued by BK and LZ. We find that the risk-adjusted profit from buying and delta hedging call options on foreign exchange futures is significantly negative. By contrast, this profit attenuates substantially (becomes smaller in absolute value)

[3] Solnik (1974), Stulz (1981), and Adler and Dumas (1983) show that deviations from purchasing power parity can create priced foreign exchange risk.

[4] Exchange rate levels certainly influence the value of firms, as investigated by Choi and Prasad (1995) and Bodnar and Wong (2003), among many others.

after controlling for loadings on realized foreign exchange volatility. Therefore, the failure of conventional risk-adjustment to eliminate the significant delta hedging errors reflects the deficiency of APMs to explain volatility risk.

Second, consistent with the prediction of the international ICAPM, we show that realized foreign exchange volatility—especially that of the Japanese yen/U.S. dollar rate—forecasts stock returns in both U.S. and international markets. The predictive power remains significant after controlling for commonly used predictive variables and in subsamples. This result suggests that foreign exchange volatility is a potentially important concern for hedging plans.

Lastly, we use a procedure similar to that of Ang et al. (2006) to directly test whether the cross section of stock returns prices volatility changes. We find that stocks with high sensitivity to innovations in implied foreign exchange volatility tend to have low expected returns; the difference is statistically significant for options on Japanese yen/U.S. dollar futures. This result is consistent with the negative volatility risk premium implied by the delta hedging error. As they fail to explain the delta hedging error, standard APMs fail to explain the differences in returns. This cross sectional effect of foreign exchange volatility risk is distinct from the effect created by stock market volatility risk documented by Ang et al. (2006). That is, foreign exchange volatility continues to be important after controlling for stock market volatility. Therefore, foreign exchange volatility risk is priced.

Among the exchange rates we study, Japanese yen/U.S. dollar volatility has the strongest predictive power for stock returns in both time-series and cross sectional regressions. The importance of Japan in international trade and finance appears to suggest that foreign exchange volatility is priced because of its pervasive influence on investment opportunities.

The remainder of the paper is organized as follows: Section I describes the data while Section II defines and characterizes delta hedging errors. Section III investigates whether foreign exchange volatility risk is priced in stock markets and Section IV offers some concluding remarks.

I. Data

The Chicago Mercantile Exchange (CME) provided daily data from quarterly futures and options-on-futures contracts on four exchange rates: the Deutsche mark (DEM), Japanese yen (JPY), Swiss franc (CHF), and British pound (GBP) versus the U.S. dollar (USD). These futures contracts expire in March, June, September, and December. To construct a series of the most liquid contracts, the futures and options contract data are spliced in the usual way at the beginning of each expiration month. That is, on each day prior to a delivery month, the settlement prices (collected at 2:00 p.m. central time) for the nearest-to-delivery futures contract are extracted. At the beginning of each delivery month, the next-to-nearest contract is substituted to avoid illiquidity around delivery. For example, the March contract data are used for all trade dates between the first day of December and the last day of February. Options and futures prices are available over the period March 1985 to June 2001 for the GBP, February 1984 to July 1999 for the DEM, March 1986 to June 2001 for the JPY, and March 1985 to June 2001 for the CHF. The Bank for International Settlements supplied daily U.S. interest rates.

Monthly realized foreign exchange variance is the sum of squared log returns within a month, calculated with intra-day data provided by the New York Fed. The New York Fed data run from 1975 to 1999 and were collected at 9 a.m., 12 p.m., 2 p.m., and 4 p.m., and are filtered to remove obvious outliers. To check the robustness of the variance measure, we also use intra-day data provided by Olsen and Associates, which consist of 5-minute returns from February 1986 to October 2004. The Olsen and New York Fed data were spliced to create a consistent daily exchange rate variance series and then aggregated to monthly frequency. We find essentially the same results using the spliced realized variance; for brevity, these results are available on request.

The Center for Research on Security Prices (CRSP) provided monthly value-weighted U.S. stock market returns (VWRET) and the Fama and Bliss risk-free rate. Morgan Stanley Capital International (MSCI) was the source for monthly gross return indices in local currencies and the International Monetary Fund (IMF) supplied the yield on Treasury bills—a proxy for the risk-free rate—for the U.K., Germany, Japan, and Switzerland. We construct monthly stock market variance with daily CRSP stock market returns for the U.S. and daily MSCI stock index returns for the U.K., Germany, Japan, and Switzerland.[5] The equity return and factor data begin in January 1974 and end in December 2002. Therefore, the availability of realized and implied foreign exchange volatility determines the length of the samples in the study.

[Insert Table I here]

Table I provides summary statistics of monthly realized foreign exchange variances for the GBP (σ^2_{GBP}), the DEM (σ^2_{DEM}), the JPY (σ^2_{JPY}), and the CHF (σ^2_{CHF}). The table also reports those statistics for the U.S. excess stock market return (ER) as well as its predictors, including U.S. realized stock market variance (σ^2_{MKT}), the U.S. term spread (TERM), and the U.S. stochastically detrended risk-free rate (RREL).[6] The term spread is produced by International Financial Statistics. The stochastically detrended risk-free rate is the risk-free rate less its average

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[5] For comparison with some earlier studies, we use the U.S. stock market return as the market portfolio. However, we find essentially the same results by using the MSCI world stock return instead. This result is not surprising: The U.S. stock market return has a correlation of 0.87 with the MSCI world stock return and the realized variances of the two markets have a correlation coefficient of 0.83.

[6] Stock forecasting results in this paper are robust to the inclusion of Lettau and Ludvigson's (2001) consumption-wealth ratio (CAY), the dividend yield, and the default premium, as predictors.

over the past 12 months. Guo (2006a) provides more information about these variables. Data exist for all the variables from May 1975 through September 1999.

Table I shows that foreign exchange variances are fairly persistent, with first-order autocorrelation from 0.47 to 0.54. We reject the null hypothesis that foreign exchange variances have a unit root but omit the full results for brevity. The realized variances of the European exchange rates (the DEM, CHF, and GBP) have a negative, albeit weak, correlation with U.S. excess stock market returns. The correlation coefficient is about 0.12 for JPY variance, however. Similarly, DEM and CHF exchange rate variances are moderately correlated with U.S. stock market variance but JPY variance has a sizable correlation of 0.40 with U.S. stock variance. Finally, realized foreign exchange variances are strongly cross-correlated among the GBP, the DEM, and the CHF, with correlations ranging from 0.59 to 0.82. By contrast, realized JPY variance is much less correlated with other foreign exchange variances. That is, JPY variance is behaviorally distinct from European exchange rate variances. Further analysis will confirm this.

II. Delta Hedging Errors

Researchers have studied the relation between volatility risk premia and delta hedging errors in a number of ways. Melino and Turnbull (1990, 1995) report that permitting a volatility risk premium improves delta hedging performance for currency options. More recently, researchers have investigated the price of volatility risk in asset markets by examining whether functions of option returns—mostly mean delta hedging errors or straddles—are non-zero. Coval and Shumway (2001) conclude that the risk-free interest rate and stock returns cannot explain equity option returns and that there must be an additional risk factor.[7] BK show that

[7] Using S&P 500 index options from 1986–95, Buraschi and Jackwerth (2001) study whether options span the pricing kernel. Their findings are consistent with priced risk factors such as stochastic volatility and jumps.

delta hedged returns for buying S&P 500 index options are negative. Further, they argue that the cross sectional variation in delta hedging returns and the time variation in volatility and jump risk imply that stochastic volatility risk drives these non-zero hedging returns. LZ use data on delta neutral straddles in the GBP, the EUR, the JPY, and the CHF to find that there is a negative volatility risk premium in all of these currencies across option maturities. However, Branger and Schlag (2004) have recently criticized the delta hedging error approach, arguing that non-continuous hedging and model misspecification biases the mean hedging error as a measure of volatility risk. Branger and Schlag (2004) describe biases whose signs are opposite to the mean delta hedging errors in our study, however, suggesting the price of volatility risk is actually more negative than shown below.

This section investigates two hypotheses about delta hedging errors, as developed and tested in BK and LZ, among others. First, if volatility risk is not priced, the profit from buying and delta hedging options—i.e., buying volatility risk—would have a zero mean. Second, if volatility risk is priced, delta hedging errors should have the same sign as the volatility risk premium. Moreover, delta hedging errors covary negatively with foreign exchange variance if they are the product of volatility risk.

A. Trading Strategies

We construct delta hedging errors with the nearest-the-money call option on foreign exchange futures, which is usually very liquid.[8] At the end of business day *t*, our hypothetical trader borrows from the money market and buys a call option. The trader also takes a short position in delta units of futures contracts to hedge the change in the underlying price. We use

[8] Put options or combinations of calls and puts produced very similar results.

the Black (1976) implied volatility and delta hedging ratio.[9] At the end of the next business day, t+1, the trader sells the call option back, repays the debt, and closes the futures position.

B. Trading Profits

Figure I illustrates that monthly delta hedging profits are, as expected, mostly negative with a few large gains and do not appear to be persistent. Table II provides summary statistics. Mean hedging errors are negative and highly significant for all four currencies, indicating that the options are overvalued relative to Black-Scholes theory (Black and Scholes (1972)), as in BK and LZ.[10] The significance of the mean hedging errors is robust to the use of either White heteroskedastic-consistent standard errors or Newey-West standard errors with four lags.

Consistent with the visual inspection of Figure I, delta hedging profits are right skewed, leptokurtotic, and serially uncorrelated.

[Insert Figure I here]

The lower panel of Table II shows that the delta hedging returns are closely correlated across currencies: The cross-correlations range from 0.36 for the correlation between the JPY and the GBP to 0.82 for the correlation between the DEM and the CHF. As Table I suggested, there is higher correlation between the European delta hedging errors than between any of the

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[9] The deltas calculated with the Black (1976) formula are almost identical to either the Barone-Adesi and Whaley (1987) (BAW) formula (for futures) or the Heston (1993) SV formula (for futures). The early exercise and stochastic volatility premia are negligible for near-term, near-the-money options.

[10] The quarterly splicing produces telescoping data with very weak autocorrelation in the delta hedging errors. The parameter estimates will still be consistently signed.

European hedging errors and the JPY. These positive correlations are consistent with Coval and Shumway's (2001) suggestion that delta hedging errors reflect a common volatility risk.[11]

[Insert Table II here]

C. Delta Hedging Errors and Conditional Foreign Exchange Variance

BK show that, if the volatility risk premium is proportional to conditional volatility, the delta hedging error is also proportional to conditional volatility.[12] Following BK, we test the sign of the volatility risk premium by regressing monthly delta hedging errors ($\pi_{i,t}$) on lagged realized foreign exchange variance ($\sigma^2_{i,t-1}$):

$$\pi_{i,t} = \alpha_i + \beta_i \sigma^2_{i,t-1} + \varepsilon_{i,t} \quad i = GBP, DEM, JPY, CHF \ . \tag{1}$$

If foreign exchange volatility risk carries a negative premium, the coefficient β_i should be negative. That is, options buyers require a lower return if they can avoid bearing volatility risk when volatility is high. Moreover, if delta hedging errors reflect only foreign exchange volatility risk, the constant term α_i should be zero (see proposition 2 in BK).

[Insert Table III here]

Table III reports the results of ordinary least squares (OLS) estimation of equation (1). Rows 1, 7, 13, and 19 show that, as expected, lagged realized foreign exchange variance predicts delta hedging errors. The adjusted R^2s range from 2% for the JPY to 5.8% for the GBP. Such low R^2s are to be expected in predicting volatile returns. After controlling for conditional foreign exchange variance, the constant term α_i becomes statistically insignificant for the GBP

[11] We also document a negative relation between delta hedging errors and the time to expiry. These results—omitted for brevity—are consistent with priced volatility risk and the results of BK and LZ.

[12] See equation (22) in BK.

and CHF and much less significant for the DEM and JPY (compare with Table II). These results support the hypothesis that delta hedging errors reflect foreign exchange volatility risk.

Table III shows that the variances of the European exchange rates (the GBP, DEM, and CHF) remain significant for predicting their own delta hedging errors, after we control for JPY variance, which has small effects (see rows 5, 11, and 24). Similarly, the variance of the JPY remains significant for predicting JPY hedging errors, even in the presence of other foreign exchange variances (rows 16, 17, and 18). The variances of the European currencies (GBP, DEM, and CHF) are highly correlated and have similar forecasting power for their own delta hedging errors. The collinearity between these European variances reduces their marginal forecasting power when more than one of them is used.

The conclusion that foreign exchange delta hedging errors are significantly negative and predicted by conditional foreign exchange variance is robust to using (i) subsamples, (ii) put options, (iii) a combination of put and call options, and (iv) lags of the dependent variable in equation (1). These results are omitted for brevity but are available on request.

III. Delta Hedging Errors, Foreign Exchange Volatility Risk, and Stock Returns

The previous section confirmed that delta hedging returns from options on exchange rate futures have negative means, which are stable over subsamples, and that foreign exchange variances predict their own delta hedging errors. This indicates that foreign exchange volatility risk is priced in options on foreign exchange futures.

This section examines whether other markets show evidence of priced foreign exchange volatility risk. In particular, we first determine that mean delta hedging returns are still significantly different from zero after we risk-adjust them with standard empirical APMs. The fact that standard empirical APMs fail to risk-adjust the returns to zero indicates either that the APMs are deficient or that options are mispriced. To distinguish between these two alternative explanations, we directly investigate whether foreign exchange variance is priced in stock markets. If foreign exchange variance is a priced risk factor, it should also affect stock prices. We conduct two tests: First, does foreign exchange variance predict future stock returns? If it does, we conclude that foreign exchange volatility risk is priced because it is related to future investment opportunities. Second**,** is foreign exchange variance risk priced in the cross section of stock returns? That is, do stocks with higher loadings on foreign exchange variance have lower expected returns?

A. Do Delta Hedging Errors Reflect Systematic Stock Market Risk?

This subsection investigates whether standard APMs, i.e., CAPM and Fama and French's (1993) 3-factor model, explain delta hedging errors. Merton (1973) shows that the CAPM holds only under the unrealistic assumption of constant investment opportunities.[13] To improve the CAPM's cross sectional fit, Fama and French (1993) augment it with two additional risk factors: Small-minus-big (SMB) is the return on a portfolio that is long in stocks with low market capitalization and short in stocks with high market capitalization. High-minus-low (HML) is the return on a portfolio that is long in high book-to-market ratio stocks and short in low book-to-market ratio stocks. Fama and French (1996) interpret SMB and HML as proxies for time-varying investment opportunities. However, one should note that their model is limited by its

[13] Schwert (1989) and Fama and French (1989) show that such assumptions are unrealistic. Whitelaw (1994) shows that the CAPM fails to explain the time-series of stock returns, while Fama and French (1993) reveal its deficiencies in explaining the cross section of stock returns.

empirical construction.[14]

[Insert Table IV here]

The risk-adjusted mean return to a trading strategy is the constant in a regression of excess trading profits on a set of excess portfolio returns (Jensen (1968)). Table IV reports the risk-adjusted mean trading profits. Neither the CAPM nor the Fama and French 3-factor model explain the delta hedging errors on options on foreign exchange futures. Jensen's α is always significantly negative—i.e., the returns cannot be explained—and the hedging errors usually have negligible loadings on risk factors. Unsurprisingly, the Gibbons, Ross, and Shanken (GRS) (1989) joint test overwhelmingly rejects the null that the pooled constants are zero for both models. These results are consistent over subsamples; we omit subsample results for brevity.

B. Do Predictors of Stock Market Returns Forecast Delta Hedging Errors?

Table IV shows that standard APMs do not explain delta hedging errors. This is puzzling but probably reflects the limitations of the CAPM and Fama-French models. This subsection provides an alternative test. If delta hedging errors reflect systematic risk, they should be predictable by financial variables that track time-varying equity premia. That is, stock market predictors might predict delta hedging errors on foreign exchange options. While this is not a formal test, if delta hedging errors are predictable by standard stock return predictors, then delta hedging errors might reflect systematic risk.

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[14] Adding the momentum profit, as suggested by Jegadeesh and Titman (1993) and Carhart (1997), and the liquidity risk, as suggested by Pastor and Stambaugh (2003), has no material effect on our main findings. We exclude these additional factors from the reported results because they are statistically insignificant.

We consider several variables that are commonly used to forecast U.S. stock market returns: U.S. realized stock market variance ($\sigma^2_{MKT,t-2}$), the U.S. term spread ($TERM_{t-1}$), and the U.S. stochastically detrended risk-free rate ($RREL_{t-1}$).[15]

Rows 2, 8, 14, and 20 of Table III show that these forecasting variables have negligible forecasting power for delta hedging errors. The results are essentially the same after we add realized foreign exchange variance to the forecasting regression, which remains significantly negative (rows 3, 9, 15, and 21). Standard predictors of stock market returns do not explain delta hedging errors. This is consistent with the failure of standard risk adjustment to explain negative delta hedging errors.

C. Foreign Exchange Variance and Stock Market Returns

Standard APMs do not explain the delta hedging errors, which appear to mainly reflect foreign exchange volatility risk. The inadequacy of CAPM and the Fama-French models likely drives this finding, however. To address this issue, we should directly examine whether foreign exchange volatility systematically predicts stock returns. Detemple and Selden (1991), Coval and Shumway (2001), and Vanden (2004) argue that if options are nonredundant assets because stochastic volatility is priced, such risk should be detectable in other financial markets. Ang et al. (2006), for example, investigate directly whether VIX affects expected stock returns.

As a first step, this subsection investigates whether realized foreign exchange variance ($\sigma^2_{i,t-1}$) forecasts one-month-ahead U.S. excess stock market return ($ER_{US,t}$):

$$ER_{US,t} = a + b * \sigma^2_{i,t-1} + C * X_{t-1} + \varepsilon_t,\ i = GBP, DEM, JPY, CHF\ , \qquad (2)$$

[15] We lag stock market variance by two months following Ghysels, Santa-Clara, and Valkanov (2005). Our main results are not sensitive to such choices, however.

where X_{t-1} is a vector of predictive variables—which include U.S. realized stock market variance, the U.S. term spread, and the U.S. stochastically detrended risk-free rate—and ε_t is a forecasting error. Section III.E will show that this specification is consistent with the international ICAPM, in which foreign exchange risk is priced. If foreign exchange variance predicts stock market returns in (2), then foreign exchange volatility risk might be priced because it covaries with investment opportunities (Campbell (1993)).

[Insert Table V here]

Table V reports the ordinary least squares (OLS) regression results of equation (2) for the period June 1975 to October 1999. When realized foreign exchange variance is the only regressor, it is a significant (the JPY, row 7) or marginally significant (the DEM and CHF, rows 4 and 10, respectively) predictor of U.S. stock market returns.

Foreign exchange variance might forecast U.S. stock market returns because it covaries with the other risk factors. After we add the other predictive variables, including realized stock market variance, Table V shows that realized foreign exchange variance remains significant at the 1% level for the JPY (row 9) or marginally significant for the DEM (row 6) and CHF (row 12). Realized stock market variance and the stochastically detrended risk-free rate are usually statistically significant (see rows 3, 6, 9, and 12), as in previous studies. These results indicate that foreign exchange variances, especially that of the JPY, significantly predict future U.S. excess stock market returns.[16]

[16] These results are robust to the use of log foreign exchange and stock market variances, as well as over two subsamples: June 1975 to December 1987 and January 1988 to October 1999. These alternative specifications produce essentially the same result for JPY but attenuate the forecasting ability of the other realized foreign exchange variances. These robustness results are omitted for brevity.

We also investigate whether realized foreign exchange variances forecast British, German, Japanese, and Swiss stock market returns denominated in the local currency. Table VI displays the results from regressing excess international stock market returns on the respective realized foreign exchange variance and control variables:

$$ER_{i,t} = a + b * \sigma_{i,t-1}^{2} + C * X_{i,t-1} + \varepsilon_{i,t}, \; i = GBP, DEM, JPY, CHF. \qquad (3)$$

Estimation of (3) uses the country-specific realized stock market variance, the stochastically detrended risk-free rate, and the term spread. Realized foreign exchange variance is again a significant (JPY, panel C) or a marginally significant (DEM, panel B) predictor of excess stock market returns in the respective countries.

[Insert Table VI here]

To summarize, realized JPY variance significantly forecasts both U.S. and international stock market returns. JPY volatility could be a priced risk factor because it covaries with investment opportunities (e.g., Campbell (1993)). We address this issue next.

D. Implied Foreign Exchange Volatility and the Cross Section of Stock Returns

Detemple and Selden (1991), among others, show that, if options are nonredundant assets because stochastic volatility is priced, returns to other financial assets should depend on their exposure to volatility risk. For example, to hedge volatility risk, investors can buy (sell) stocks whose returns are positively (negatively) correlated with volatility. Therefore a negative price of volatility risk implies that stocks with high loadings on foreign exchange volatility should have lower expected returns than stocks with low loadings.[17]

[17] Vanden (2004), for example, tested whether index option returns, which are mainly determined by volatility changes, explain the cross section of stock returns.

In this subsection, we directly investigate whether foreign exchange volatility risk is priced in the cross section of stock returns using a procedure similar to that of Ang et al. (2006). In particular, we regress daily U.S. individual stock returns on a constant, daily U.S. excess stock market returns, and daily changes in implied foreign exchange volatility:

$$r_{i,t,k} = \alpha_{i,t} + \beta_{i,1,t} ER_{t,k} + \beta_{i,2,t} \Delta IV_{t,k} + \varepsilon_{i,t,k} , \tag{4}$$

where $r_{i,t,k}$ is the log excess return on stock *i* in the k^{th} trading day of month *t*, $ER_{t,k}$ is the log excess return on the CRSP value-weighted market index used as a proxy for the aggregate stock market return, and $\Delta IV_{t,k} = IV_{t,k} - IV_{t,k-1}$ is the first difference of daily implied foreign exchange volatility.[18] The daily excess return is the difference between the daily stock return and the daily risk-free rate. The daily risk-free rate is the constant value that compounds to the one-month Fama and Bliss risk-free rate.

We use all common stocks in the CRSP database, including those listed on NYSE, AMEX, and NASDAQ. At the beginning of each month, we estimate equation (4) using daily return data from the previous month. To facilitate estimation of factor loadings, we drop stocks that have less than 18 daily return observations within the month. We then sort stocks equally into five portfolios (quintiles), according to their sensitivities to implied foreign exchange volatility, $\beta_{i,2,t}$; we hold the stocks for one month out of sample, value-weighting within the quintile at the beginning of the holding period. If higher volatility indicates poorer investment opportunities, investors might want to buy (short) stocks that have high (low) loadings on

[18] Ang at el. (2006) find no significant risk premium if they use daily realized stock market variance constructed using high-frequency data. We find similar results for realized foreign exchange variance. To conserve space, we do not report these results here but they are available on request.

volatility. Thus, stocks most sensitive to innovations in implied foreign exchange volatility should have lower expected returns.

[Insert Table VII here]

Table VII reports the simple returns on the quintile portfolios for the four foreign exchange implied volatilities. The first (fifth) quintile has the lowest (highest) loadings on implied volatility. As a benchmark for the foreign exchange results, we replicate Ang et al. (2006) results, with an extended sample from February 1986 to October 2004, by sorting stocks according to their sensitivities to implied stock market volatility, VIX. Consistent with Ang et al., the risk premium of stock market volatility—the difference between the returns on the fifth and first quintiles—is significantly negative (row labeled "VIX", panel A). It remains significantly negative after controlling for market risk (panel B), the Fama-French 3 factors (panel C), and a five-factor model (panel D). The five-factor model consists of the Fama-French 3 factors, the UMD (up-minus-down) momentum factor provided by Kenneth French, and the liquidity factor by Pastor and Stambaugh (2003).

Table VII shows that JPY implied variance provides results very similar to those of VIX. Portfolios with heavy loadings on JPY implied volatility tend to have low expected returns, and the difference between the fifth and first quintile portfolio returns is a significant -0.69 percent per month (panel A). Therefore, consistent with negative delta hedging errors reported in Section II, the cross sectional tests indicate that JPY volatility carries a negative risk premium.

Panel E of Table VII shows that the first and fifth quintiles sorted by implied JPY volatility usually consist of small stocks, similar to the portfolios sorted by VIX. Small stocks are usually less liquid than big stocks. However, panels B through D show that the difference remains significantly negative after controlling for risk factors such as the market return, the value premium, the size premium, the momentum profit, and liquidity risk. These results are expected, as these risk factors have poor explanatory power for delta hedging errors.

The risk premia on implied volatility for the other three foreign exchanges are usually negative, albeit statistically insignificant. The insignificant point estimates could indicate a power problem resulting from the fact that the other foreign exchanges are much less important in global finance than JPY. The differential is consistent with results in Tables V and VI that show that JPY realized variance is the best predictor of U.S. and international stock market returns among foreign exchange variances.

One might think that JPY volatility is priced in Table VII because it proxies for U.S. stock market volatility: The two variables have a correlation coefficient of 0.4 in Table I. To address this issue, we control for VIX in the estimation of stock return sensitivity to innovations in implied foreign exchange volatility:

$$r_{i,t,k} = \alpha_{i,t} + \beta_{i,1,t} MKT_{t,k} + \beta_{i,2,t} \Delta IV_{t,k} + \beta_{i,3,t} \Delta VIX_{t,k} + \varepsilon_{i,t,k} \ . \qquad (5)$$

Those results—omitted for brevity but available on request—are consistent with those reported in Table VII. Similarly, VIX retains its role as a priced risk factor when we control for implied foreign exchange volatility. Our results seem to suggest that both stock market volatility and JPY volatility are important, but independent, risk factors. This interpretation is consistent with the fact that both volatilities forecast U.S. stock returns (Table V).

The cross sectional results in Table VII are robust to different measurements of innovations to implied foreign exchange volatility. For example, using the residual of an AR(1) model of implied volatility or log changes in implied volatility does not meaningfully change the reported results. Implied variance produces results similar to those of implied volatility. The results are stable across time: The difference between the fifth and first quintiles is a significant -

0.5 percent in the first half of the sample and a marginally significant -0.9 percent in the second half of the sample for the JPY.

Table VII is also robust to the use of a double sorting procedure. First, we sort all CRSP stocks equally into quintile portfolios by loading on changes in VIX; then, within each quintile, we sort stocks equally into quintile portfolios by loading on changes in implied FX volatility. After controlling for loadings on VIX, loadings on USD/JPY volatility still carry a negative risk premium. To summarize, the cross section of stock returns prices JPY volatility.

E. Discussion

JPY volatility risk is significantly priced in both options markets and stock markets. But why is foreign exchange volatility risk priced? One possible explanation is that the price of volatility risk stems from priced foreign exchange risk in levels. This subsection illustrates the point using Ng's (2004) international ICAPM, which synthesizes Campbell's (1993) ICAPM and the international APMs of Solnik (1974), Stulz (1981), and Adler and Dumas (1983). Ng shows that the conditional covariance of any asset return with *L* exchange rates, the market portfolio, and *K* state variables, determines its conditional excess return, $E_t r_{j,t+1} - r_{f,t+1}$:

$$E_t r_{j,t+1} - r_{f,t+1} = \sum_{l=1}^{L} \lambda_l^F \operatorname{cov}[r_{j,t+1}, e_{l,t+1}] + \lambda_m \operatorname{cov}[r_{j,t+1}, r_{m,t+1}] + \sum_{k=1}^{K} \lambda_k^S \operatorname{cov}[r_{j,t+1}, S_{k,t+1}], \tag{6}$$

where λ is the price of risk, $e_{l,t+1}$ is the *l*th exchange rate, $r_{m,t+1}$ is the market return, and $S_{k,t+1}$ is a state variable that forecasts stock market returns and foreign exchanges.

If the beta of the asset return with respect to a factor—e.g., $\beta_{jl,t+1} = \dfrac{\operatorname{cov}[r_{j,t+1}, e_{l,t+1}]}{\operatorname{var}[e_{l,t+1}]}$—is approximately constant, then the conditional excess return to any asset ($E_t r_{j,t+1} - r_{f,t+1}$) is approximately a linear function of the conditional variances of foreign exchanges, stock market returns, and the state variables:

$$E_t r_{j,t+1} - r_{f,t+1} = \sum_{l=1}^{L} \lambda_l^F \beta_{jl} \text{ var}[e_{l,t+1}] + \lambda_m \beta_{jm} \text{ var}[r_{m,t+1}] + \sum_{k=1}^{K} \lambda_k^S \beta_{jk} \text{ var}[S_{k,t+1}] . \quad (7)$$

Equation (7) implies that if foreign exchange level exposure is priced and its conditional variance is persistent (predictable), then that conditional variance will predict excess returns on any asset, including excess stock market returns and delta hedging errors. Consistent with this hypothesis, realized foreign exchange variance does forecast stock market returns (Tables V and VI). Therefore foreign exchange volatility might be a priced risk factor because it comoves with investment opportunities (Campbell (1993)). However, the positive relation between foreign exchange variance and future stock market returns suggests that foreign exchange volatility should carry a positive risk premium, instead of the negative one documented in this paper.

This puzzle is similar to that documented for stock market volatility: Although realized stock market variance is positively correlated with stock market returns, most authors find that stock market volatility risk carries a negative risk premium. Therefore, as with stock market volatility risk, foreign exchange volatility risk must affect investment opportunities through other channels. For example, if the foreign exchange level is a priced risk factor, a higher level of foreign exchange volatility might indicate poorer investment opportunities because it makes hedging foreign exchange level risk more difficult. Presumably, risk-averse investors dislike volatile states of the world and are willing to pay a premium to buy options to hedge foreign exchange volatility risk, as suggested by Coval and Shumway (2001).

> "*Because investors presumably dislike volatile states of the world, assets with negative volatility betas or assets that lose value when volatility increases are relatively risky assets. … [B]ecause straddles insure investors against volatile states of the world, if*

there is a risk premium for volatility risk, expected zero-beta straddle returns will be less than the risk-free rate." — Coval and Shumway (2001, p. 995)

IV. Conclusion

This paper investigates whether foreign exchange volatility risk is priced in equity markets in three ways. First, risk-adjustment by CAPM and Fama-French factors fails to explain the positive returns to a trading strategy of selling and delta hedging at-the-money call options. Second, JPY realized foreign exchange variance forecasts stock market returns, indicating that it might be a priced factor in ICAPM. Third, using a procedure similar to Ang et al. (2006), we find JPY implied foreign exchange volatility is negatively priced in the cross section of stocks. We emphasize that these results are quite stable over subsamples and robust to alternative specifications. They are not due to some particular episode or period. Overall, our results support the hypothesis that JPY foreign exchange volatility risk is priced independently of equity market volatility and carries a negative risk premium.

Commonly used risk factors fail to account for delta hedging errors, which reflect volatility risk. Similarly, these models fail to explain returns on the portfolios sorted on sensitivity to implied foreign exchange volatility. Therefore, if foreign exchange volatility risk is priced systematically, it should be included in an APM. Vanden (2004) explores this issue for stock market volatility risk and his tentative results appear to be encouraging. A formal analysis along this line for foreign exchange volatility risk seems to be warranted and we leave it for future research.

The evidence that volatility risk carries a negative risk premium in equity markets appears to be intuitive because it is potentially consistent with Merton's ICAPM. However, existing finance theory has not established exact economic mechanisms through which volatility risk affects asset prices yet.

In combining foreign exchange and equity market data, our approach is broadly consistent with that of Bakshi, Carr, and Wu (2007), who argue that when domestic securities, such as bonds and stocks, do not complete the market, currency and currency options can help one understand the multidimensional nature of risk. Because foreign exchange volatility is priced in the stock market, it appears that stocks and foreign exchange share at least some risk factors, which appear to be global in nature.

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Table I: Summary Statistics

	ER	σ^2_{MKT}	TERM	RREL	σ^2_{GBP}	σ^2_{DEM}	σ^2_{JPY}	σ^2_{CHF}
Panel A. Univariate Statistics								
Mean (%)	0.752	0.140	1.741	-0.004	0.103	0.091	0.100	0.124
Standard Deviation (%)	4.353	0.139	1.296	0.111	0.088	0.068	0.092	0.096
AR1	0.024	0.484	0.940	0.811	0.499	0.471	0.494	0.535
Panel B. Cross-Correlation								
ER	1.000							
σ^2_{MKT}	-0.255	1.000						
TERM	0.079	-0.025	1.000					
RREL	-0.180	-0.077	-0.582	1.000				
σ^2_{GBP}	-0.096	0.000	0.144	-0.052	1.000			
σ^2_{DEM}	-0.077	0.136	-0.010	0.043	0.723	1.000		
σ^2_{JPY}	0.119	0.404	-0.262	-0.007	0.160	0.332	1.000	
σ^2_{CHF}	-0.063	0.147	-0.087	0.084	0.586	0.824	0.390	1.000

Notes: The table reports summary statistics of U.S. excess stock market return, ER, U.S. realized stock market variance (σ^2_{MKT}), the U.S. term spread (TERM), the U.S. stochastically detrended risk free rate (RREL), and realized variance of U.S. dollar foreign exchange rates versus the GBP (σ^2_{GBP}), DEM (σ^2_{DEM}), JPY (σ^2_{JPY}), and CHF (σ^2_{CHF}). The monthly sample spans the period May 1975 through September 1999.

Table II: Summary Statistics of Monthly Delta Hedging Profits

Panel A: Moments of Monthly Delta Hedging Profits

Mean	Standard Deviation	Minimum	Maximum	Skewness	Kurtosis	AR1
British Pound/U.S. Dollar: March 1985 to June 2001						
-0.302***	0.667	-2.849	2.903	0.525	3.132	-0.056
Deutsche Mark/U.S. Dollar: February 1984 to July 1999						
-0.143***	0.253	-0.723	0.825	0.980	2.067	-0.09
Japanese Yen/U.S. Dollar: March 1986 to June 2001						
-0.152***	0.367	-0.944	1.086	0.652	0.817	-0.030
Swiss Franc/U.S. Dollar: March 1985 to June 2001						
-0.108***	0.308	-0.865	1.695	1.440	6.250	-0.136

Panel B: Cross-correlations of Monthly Delta Hedging Profits

Currency/U.S. Dollar	British Pound	Deutsche Mark	Japanese Yen	Swiss Franc
British Pound	1.000			
Deutsche Mark	0.696	1.000		
Japanese Yen	0.359	0.428	1.000	
Swiss Franc	0.680	0.820	0.494	1.000

Notes: The table reports summary statistics of monthly delta hedging profit, which is scaled by 100, as well as cross-correlations of monthly delta hedging profits for the period February 1986 to July 1999, the longest sample in which we have data for all currencies. ***, **, and * denote significance at the 1, 5, and 10 percent level, respectively. The significance of the mean is robust to the use of either White heteroskedastic-consistent or Newey-West standard errors.

Table III: Regressions of Delta Hedging Profits on Realized Foreign Exchange Variance

	CONST	$\sigma^2_{GBP,t-1}$	$\sigma^2_{DEM,t-1}$	$\sigma^2_{JPY,t-1}$	$\sigma^2_{CHF,t-1}$	$\sigma^2_{MKT,t-2}$	$TERM_{t-1}$	$RREL_{t-1}$	Adj. R^2 (%)
					Pane1 A. British Pound/U.S. Dollar: 1985:3-1999:10				
1	-0.120	-1.804**							5.80
	(-1.354)	(-2.563)							
2	-0.335***					0.075	0.000	0.734	-1.08
	(-3.443)					(0.415)	(0.327)	(0.900)	
3	-0.221**	-2.239***				-0.182	0.001*	-0.093	6.25
	(-2.002)	(-2.918)				(-0.776)	(1.659)	(-0.103)	
4	-0.016	-0.282	-2.734***						8.09
	(-0.165)	(-0.316)	(-2.731)						
5	-0.035	-1.729**		-0.809*					6.73
	(-0.329)	(-2.606)		(-1.954)					
6	-0.011	-0.688			-1.850**				7.48
	(-0.108)	(-0.833)			(-2.511)				
					Panel B. Deutsche Mark/U.S. Dollar: 1984:2-1999:7				
7	-0.073**		-0.689***						2.84
	(-2.396)		(-2.847)						
8	-0.164***					-0.032	0.000	-0.153	-1.04
	(-3.950)					(-0.455)	(0.714)	(-0.463)	
9	-0.093**		-0.829***			-0.044	0.000	-0.327	2.99
	(-2.137)		(-3.144)			(-0.640)	(1.080)	(-0.954)	
10	-0.074**	0.093	-0.791*						2.35
	(-2.400)	(0.329)	(-1.872)						
11	-0.649*		-0.647***	-0.115					2.51
	(-1.910)		(-2.791)	(-0.959)					
12	-0.070**		-0.472		-0.204				2.38
	(-2.144)		(-0.841)		(-0.369)				
					Panel C. Japanese Yen/U.S. Dollar: 1986:3-1999:10				
13	-0.075*			-0.575**					2.00
	(-1.878)			(-2.297)					
14	-0.155**					-0.091	0.000	-0.285	-0.91
	(-2.377)					(-0.762)	(0.433)	(-0.696)	
15	-0.064			-0.754***		0.201	-0.000	-0.189	1.08
	(-0.812)			(-2.663)		(1.490)	(-0.423)	(-0.448)	
16	-0.461	-0.316		-0.552**					1.78
	(-0.842)	(-0.964)		(-2.230)					
17	-0.420		-0.425	-0.513**					1.84
	(-0.746)		(-1.085)	(-2.071)					
18	-0.071			-0.564**	-0.044				1.40
	(-1.234)			(-2.239)	(-0.124)				
					Panel D. Swiss Franc/U.S. Dollar: 1985:3-1999:10				
19	-0.003				-0.843***				3.97
	(-0.076)				(-3.138)				
20	-0.111**					-0.050	0.000	0.174	-1.23
	(-2.350)					(-0.527)	(0.370)	(0.418)	
21	-0.036				-0.898***	-0.006	0.000	-0.057	2.83
	(-0.598)				(-3.275)	(-0.061)	(0.974)	(-0.125)	
22	-0.003	-0.273			-0.605				3.74
	(-0.059)	(-0.947)			(-1.526)				
23	-0.003		-0.472		-0.472				3.57
	(-0.066)		(-0.612)		(-0.651)				
24	-0.003			0.002	-0.843***				3.41
	(-0.075)			(0.011)	(-3.086)				

Notes: The table reports the OLS estimation results of regressing one-month-ahead delta hedging profits on lagged realized foreign exchange variances, including that of the GBP ($\sigma^2_{GBP,t-1}$), DEM ($\sigma^2_{DEM,t-1}$), JPY ($\sigma^2_{JPY,t-1}$), and CHF ($\sigma^2_{CHF,t-1}$). In some specifications we also control for commonly used predictive variables of stock market returns, including U.S. realized stock market variance ($\sigma_{MKT,t-2}$), the U.S. term spread ($TERM_{t-1}$), and the U.S. stochastically detrended risk-free rate ($RREL_{t-1}$). White-corrected t-statistics are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent level, respectively. The constant term is scaled by 100. The adjusted R^2s are in percentage terms.

Table IV: Jensen's Alpha Test for Delta Hedging Profits

	Constant	ER	SMB	HML
Panel A. British Pound/U.S. Dollar: March 1985 to June 2001				
1	-0.302***			
	(-6.360)			
2	-0.284***	-0.024**		
	(-5.922)	(-2.187)		
3	-0.285***	-0.022	0.030**	0.012
	(-5.752)	(-1.453)	(2.153)	(0.683)
Panel B. Deutsche Mark/U.S. Dollar: February 1984 to July 1999				
4	-0.143***			
	(-7.759)			
5	-0.140***	-0.004		
	(-7.540)	(-0.809)		
6	-0.141***	-0.003	0.001	0.003
	(-7.263)	(-0.563)	(0.172)	(0.433)
Panel C. Japanese Yen/U.S. Dollar: March 1986 to June 2001				
7	-0.152***			
	(-5.634)			
8	-0.150***	-0.002		
	(-5.653)	(-0.426)		
9	-0.151***	-0.002	-0.000	0.002
	(-5.466)	(-0.256)	(-0.030)	(0.150)
Panel D. Swiss Franc/U.S. Dollar: March 1985 to June 2001				
10	-0.108***			
	(-4.940)			
11	-0.102***	-0.009		
	(-4.652)	(-1.407)		
12	-0.100***	-0.010	-0.004	-0.005
	(-4.365)	(-1.430)	(-0.560)	(-0.585)
Panel E: Joint Test: March 1986 to July 1999				
CAPM: GRS=15.449 (0.000)				
Fama and French 3-Factor Model: GRS=14.840 (0.000)				

Note: The table reports Jensen's α test for monthly delta hedging profits. The dependent variable, the delta hedging return, is regressed on (1) a constant; (2) a constant, and the stock market return (ER) for CAPM; (3) a constant, the stock market return (ER), the size premium (SMB), and the value premium (HML) from the Fama and French (1993) 3-factor model. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. In panels A through D we report White-corrected t-statistics in parentheses. Panel E reports the Gibbons, Ross, and Shanken (GRS) (1989) test that the intercepts are jointly equal to zero, with p-values in parenthesis. The constant term is scaled by 100.

Table V: Do Foreign Exchange Variances Predict U.S. Excess Stock Returns?

	$\sigma^2_{GBP,t-1}$	$\sigma^2_{DEM,t-1}$	$\sigma^2_{JPY,t-1}$	$\sigma^2_{CHF,t-1}$	$\sigma^2_{MKT,t-2}$	$TERM_{t-1}$	$RREL_{t-1}$	Adj. R^2 (%)
				Pane1 A. British Pound/U.S. Dollar				
1	0.775							-0.32
	(0.338)							
2	1.161				5.683***			2.63
	(0.607)				(4.517)			
3	0.893				5.198***	-0.000	-5.031*	3.40
	(0.386)				(3.911)	(-0.173)	(-1.667)	
				Panel B. Deutsche Mark/U.S. Dollar				
4		5.621*						0.44
		(1.925)						
5		4.886*			5.492***			3.17
		(1.683)			(4.394)			
6		5.308*			4.979***	-0.000	-5.252*	4.07
		(1.823)			(3.784)	(-0.184)	(-1.732)	
				Panel C. Japanese Yen/U.S. Dollar				
7			8.549***					2.96
			(4.176)					
8			6.075**		3.973***			3.96
			(2.471)		(2.641)			
9			6.678***		3.579**	0.001	-4.196	4.94
			(2.656)		(2.453)	(0.398)	(-1.386)	
				Panel D. Swiss Franc/U.S. Dollar				
10				4.105*				0.48
				(1.701)				
11				3.584	5.488***			3.20
				(1.503)	(4.378)			
12				4.113*	4.994***	-0.000	-5.247*	4.19
				(1.741)	(3.802)	(-0.093)	(-1.745)	

Notes: The table reports the OLS estimation results of regressing one-month-ahead U.S. excess stock market returns on realized foreign exchange variances, including that of the GBP ($\sigma^2_{GBP,t-1}$), DEM ($\sigma^2_{DEM,t-1}$), JPY ($\sigma^2_{JPY,t-1}$), and CHF ($\sigma^2_{CHF,t-1}$) (see equation (2)). The sample spans the period June 1975 through September 1999. In some specifications we also control for commonly used predictive variables, including U.S. realized stock market volatility ($\sigma_{MKT,t-2}$); the U.S. term spread ($TERM_{t-1}$); and the U.S. stochastically detrended risk-free rate ($RREL_{t-1}$). White-corrected t-statistics are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent level, respectively. The adjusted R^2s are in percentage terms.

Table VI: Do Foreign Exchange Variances Predict International Excess Stock Returns?

	$\sigma^2_{GBP,t-1}$	$\sigma^2_{DEM,t-1}$	$\sigma^2_{JPY,t-1}$	$\sigma^2_{CHF,t-1}$	$\sigma^2_{MKT,t-2}$	$TERM_{t-1}$	$RREL_{t-1}$	Adj. R^2 (%)
Pane1 A. British Excess Stock Market Returns								
1	0.157							-0.34
	(0.114)							
2	0.215				1.369***			0.49
	(0.155)				(2.936)			
3	0.647				1.640***	0.001	1.050	0.60
	(0.451)				(3.506)	(1.405)	(1.028)	
Panel B. German Excess Stock Market Returns								
4		3.302*						0.60
		(1.732)						
5		3.098			0.512			0.91
		(1.605)			(1.100)			
6		4.083**			0.500	0.001*	-1.704	1.79
		(2.086)			(1.008)	(1.770)	(-1.374)	
Panel C. Japanese Excess Stock Market Returns								
7			3.125**					1.20
			(2.160)					
8			3.243**		-0.186			0.91
			(2.175)		(-0.296)			
9			3.646**		-0.237	0.000	-2.462*	1.40
			(2.446)		(-0.363)	(0.072)	(-1.816)	
Panel D. Swiss Excess Stock Market Returns								
10				1.250				-0.00
				(0.983)				
11				1.191	0.204			-0.24
				(0.937)	(0.527)			
12				1.307	0.209	0.001	-0.218	-0.47
				(1.005)	(0.525)	(0.895)	(-0.169)	

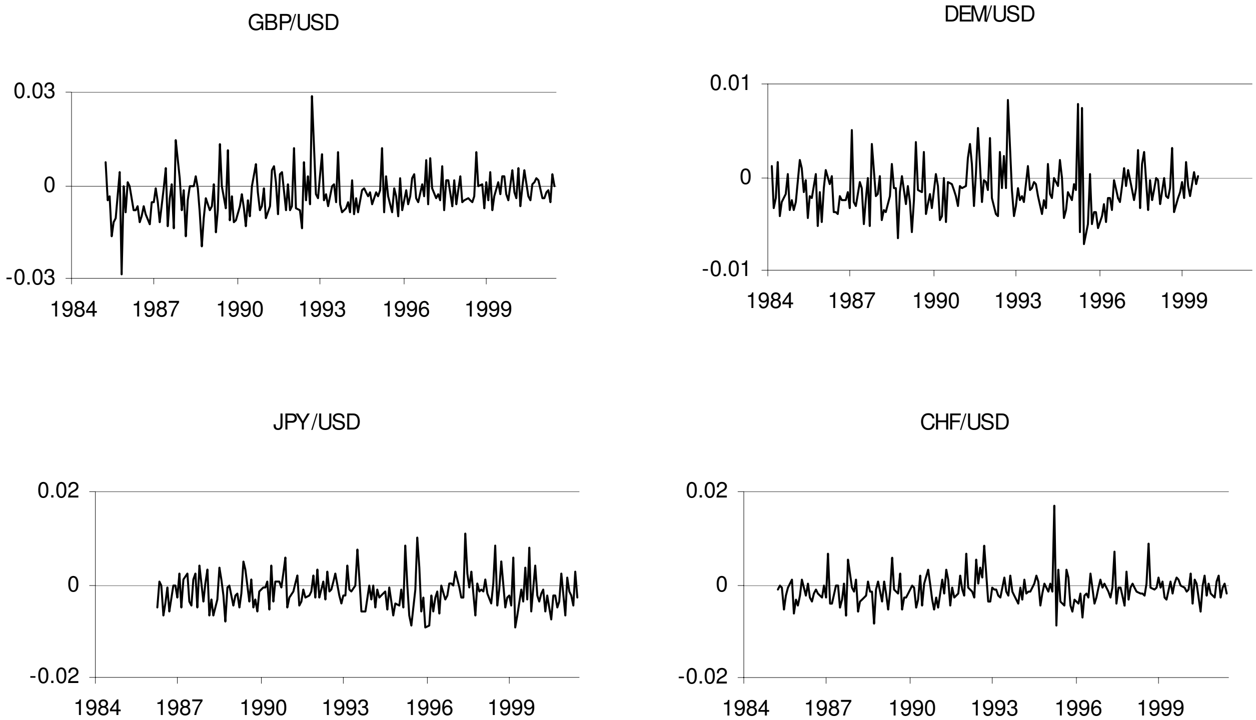
Notes: The table reports the OLS estimation results of regressing one-month-ahead international excess stock market returns on realized foreign exchange variances, including that of GBP ($\sigma^2_{GBP,t-1}$) in panel A, DEM ($\sigma^2_{DEM,t-1}$) in panel B, JPY ($\sigma^2_{JPY,t-1}$) in panel C, and CHF ($\sigma^2_{CHF,t-1}$) in panel D (see equation (3)). The sample spans the period June 1975 through September 1999. The gross return indices are from the United Kingdom, Germany, Japan, and Switzerland in panels A through D, respectively. In some specifications we also control for commonly used predictive variables, including realized stock market variance ($\sigma^2_{MKT,t-2}$), the stochastically detrended risk-free rate ($RREL_{t-1}$), and the term spread ($TERM_{t-1}$). We use country-specific data for all the countries. White-corrected t-statistics are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively. The adjusted R^2s are in percentage terms.

Table VII: Is Implied Foreign Exchange Volatility Priced in the Cross Section of Stocks?

	1	2	3	4	5	5-1
			Panel A. Mean Returns			
GBP	1.21 ***	1.26 ***	1.33 ***	1.37 ***	1.09 **	-0.13
	[0.45]	[0.32]	[0.31]	[0.31]	[0.44]	[0.27]
JPY	1.42 ***	1.31 ***	1.27 ***	1.28 ***	0.73	-0.69 **
	[0.46]	[0.33]	[0.32]	[0.34]	[0.48]	[0.27]
DEM	1.35 ***	1.40 ***	1.43 ***	1.54 ***	1.47 ***	0.10
	[0.42]	[0.31]	[0.30]	[0.32]	[0.41]	[0.19]
CHF	1.30 ***	1.31 ***	1.30 ***	1.43 ***	1.23 ***	-0.07
	[0.44]	[0.32]	[0.30]	[0.33]	[0.44]	[0.22]
VIX	1.61 ***	1.19 ***	1.18 ***	0.96 ***	0.53	-1.07 ***
	[0.42]	[0.30]	[0.29]	[0.33]	[0.47]	[0.27]
			Panel B. CAPM Alpha			
GBP	-0.14	0.06	0.19 **	0.18 **	-0.29	-0.15
JPY	0.17	0.22 ***	0.20 ***	0.18 **	-0.59 ***	-0.76 ***
DEM	-0.13	0.05	0.15 **	0.21 ***	-0.03	0.10
CHF	-0.07	0.13	0.17 *	0.22 ***	-0.17	-0.10
VIX	0.47 ***	0.21 **	0.22 ***	-0.07	-0.69 ***	-1.16 ***
			Panel C. Fama and French 3-Factor Alpha			
GBP	0.08	0.04	0.08	0.17 **	-0.09	-0.17
JPY	0.31 *	0.18 ***	0.15 **	0.12	-0.42 **	-0.73 **
DEM	0.07	0.06	0.08	0.20 ***	0.16	0.09
CHF	0.15	0.07	0.06	0.20 ***	0.04	-0.11
VIX	0.53 ***	0.17 **	0.16 ***	-0.08	-0.49 **	-1.02 ***
			Panel D. Five-Factor Alpha			
GBP	0.16	0.10	0.06	0.17 **	0.16	0.00
JPY	0.37 ***	0.17 **	0.07	0.15 **	-0.16	-0.54 **
DEM	0.21	0.07	0.07	0.22 ***	0.19	-0.02
CHF	0.22	0.09	0.15 **	0.13 *	0.17	-0.05
VIX	0.63 ***	0.09	0.06	0.09	-0.02	-0.65 **
			Panel E: Market Share			
GBP	8.8	25.7	29.6	26.2	9.8	1.0
JPY	9.3	25.9	30.2	25.8	8.9	-0.4
DEM	7.6	25.8	31.1	26.8	8.7	1.1
CHF	8.8	25.6	29.2	26.9	9.5	0.7
VIX	10.4	28.7	29.9	22.9	8.1	-2.2

Notes: We regress individual log excess stock returns on a constant, log excess stock market returns, and the change in implied volatility, as in equation (4). We then sort stocks into 5 portfolios based on their sensitivity to changes in implied volatility, for example, the first quintile has the lowest loadings and the fifth quintile has the highest loadings. Returns are continuously compounded monthly simple returns in percentage terms. The columns report the adjusted return on each portfolio. The last column reports the difference between portfolio 1 and portfolio 5. Panels A through D use no risk adjustment, CAPM, the Fama and French 3-factor model, and a 5-factor model, respectively. The 5-factor model augments the Fama and French model with the momentum and liquidity factors. Panel E reports the market share of the stocks in each quintile. ***, **, and * denote significance at the 1, 5, and 10 percent levels, respectively.

Figure I: Plot of Delta Hedging Errors



Notes: The figure shows delta hedging errors of GBP/USD, DEM/USD, JPY/USD, and CHF/USD plotted at a monthly frequency. The sample periods for GBP/USD, DEM/USD, JPY/USD, and CHF/USD are 1985:03-2001:06, 1984:02-1999:07, 1986:03-2001:06, and 1985:03-2001:06, respectively.