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THE EFFECTS OF CENTRAL BANK INTERVENTION ON THE VOLATILITY OF EXCHANGE RATES: EVIDENCE FROM THE OPTIONS MARKET*

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The flexible exchange rate period officially began in 1973 with the complete collapse of the Bretton Woods agreements. It ushered in a period of intense exchange rate volatility. Since the excessive variability often affected the economy, central banks began to intervene to support the dollar in the foreign exchange market. An analysis of the effects of central bank interventions on the exchange market is presented. There have been many contradictory study results as to whether central bank interventions decrease or increase volatilities of exchange rates. We examine the intervention effects on the changes in the implied volatilities of the DM and YEN exchange rates in the foreign currency options market during the post-Louvre period.

Our main conclusions derived from our research are as follow: The effects of interventions of the Federal Reserve, Bundesbank, and Bank of Japan on changes in the implied volatilities of the DM and the YEN exchange rate were also positive and significant in the foreign currency options market. In other words, the intervention policies increased the magnitude of volatilities in the options market during the post-Louvre period.

In this sense, if the intervention purpose was to decrease the volatilities, we can conclude that the intervention policies were unsuccessful attaining their goals during the post-Louvre period.

I. INTRODUCTION

In the 1960s, under the Bretton Woods System of fixed exchange rates, central bank interventions were used to maintain the exchange rates within certain prescribed margins and was considered one of the essential parts of a central bank's policy. Over the years, there have been conspicuous changes in conducting

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the intervention. Because of the collapse of the Bretton Woods System in the early 1970s, the fixed exchange rate regime changed to one of managed floating. From that time, the scale of intervention began to increase, and sometimes several countries intervened together to support the dollar.

One important meeting for cooperative intervention is Louvre meeting. The Louvre Agreement to stabilize the currency values was signed on February 23, 1987. The G-7 (except Italy) produced the Louvre Accord which stated that nominal exchange rates should be stabilized at their current levels (G-6 Communique, February 1987). Over the post-Louvre period, central banks have coordinated their intervention efforts closely. Many study results, however, suggest that the intervention can have an effect on the exchange rate but that its effect will last only temporarily if macroeconomic policies are left unchanged.[1]

The purpose of this study is to test how central bank interventions affected the volatilities of the DM and the YEN exchange rates during the post-Louvre period. Thus, we will examine whether the central bank interventions helped to stabilize "disorderly market" conditions. We will use currency options price model to calculate changes in the implied volatilities of the DM and the YEN exchange rates. These implied volatilities are likely to provide reasonable estimates of ex ante volatility based on current market-determined prices.

This estimate will be unbiased if we assume that the options market is efficient and that the option pricing model is correct. This paper extends previous research done by Bonser-Neal and Tanner (1995). They examine the effects of central bank interventions on changes in the implied volatilities of foreign exchange rates. Since asset prices are commonly believed to react sensitively to economic news, we include several macroeconomic variables in some of our regressions to control for volatility changes that might result from factors other than those central bank interventions.

This paper differs from Bonser-Neal and Tanner (1995). In the sense that they use the Barone-Adesi-Whaley (1987) model to find implied volatilities. We, however, use the Garman-Kohlhagen (1983) model[2]. By using the same variables and same period, we can compare the results of the intervention effects on the level of changes in the implied volatilities of exchange rates.

Foreign exchange market intervention is any transaction or announcement by an official that is intended to affect the value of exchange rates. Central banks define intervention as any official sale or purchase of foreign assets against dom-

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[1] See Greene (1983a).

[2] This is the first paper in examining the intervention effects by applying American options to the European model to find implied volatilities. In the case of near- at the money call options, an American model cannot improve predictive accuracy relative to using a European model. See for example, Shastri and Tandon(1986a), Bodurtha and Courtadon(1987), Fabozzi, Hauser and Yaari(1990) and Jorion(1994).

estic assets in the foreign exchange markets. There are many empirical studies that examine whether intervention operations affect the level of exchange rates.[3] Until recently, however, advances in time series modeling and currency options theory have not been used in this context. The recent studies have begun to correct this shortcomings. This study will add to their work.[4]

II. METHODOLOGY

2.1. The Currency Options Price Model and Implied Volatility

2. 1. 1 Currency Options Price Model

In 1973, F. Black and M. Scholes[5] derived a formula to price European call options on nondividend paying stocks. The Black-Scholes option pricing model and its various extensions have been widely used both on the practical and academic sides to price various options.

The Garman-Kohlhagen (1983) model is a pricing model used to price European type currency options, i. e., those which can only be exercised at maturity. These differ from the options traded on the Philadelphia Stock Exchange (PHLX) which can be exercised any time up to and including the maturity date, i. e., American style options.

Assumptions :

1. Geometric Brownian motion governs the currency spot price: i. e., the differential representation of spot price movements is $dS = \mu S dt + \sigma S dZ$, where Z is the standard Wiener process. 2. The spot exchange rate denoted by S is assumed to be lognormally distributed over time. 3. Markets are frictionless. 4. Interest rates, both in the domestic and foreign markets, are constant.[6]

$$C_t = e^{-r_F T} S_t N(x + \sigma\sqrt{T}) - e^{-r_D T} K N(x) \qquad (1)$$

where, $x = [\ln(S/K) + (r_D - r_F - (\sigma^2/2))T] / \sigma\sqrt{T}$

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[3] See Edison (1993), Dominguez and Frankel (1993a, 1993b), Ghosh (1992), Klein and Rosengren (1991) and Obstfeld(1990).

See effects of macroeconomic announcement, for example, Edrington and Jae Ha Lee (1993), Madura and Tucker (1992), Hogan, Melvin and Roberts (1991).

[4] Bonser-Neal and Tanner (1995).

[5] See F. Black and M. Scholes (1973)

[6] The analysis could be extended without much difficulty to stochastic interest rates. In this case, volatility parameters must be redefined to incorporate the variances and covariances of interest rate movements as well as spot price movements. However, we forego this extension in the interest rate of clarity.

The notation used here is as follows:
S_t = the spot price of the deliverable currency as expressed domestic units per foreign unit. K = exercise price of the option in domestic units per foreign unit. T = time remaining until the expiration of the option. C_t = the price of a foreign exchange call option expressed in domestic units per foreign unit. r_D = the domestic riskless interest rate. r_F = the foreign riskless interest rate. σ = the instantaneous standard deviation of the relative changes in the spot currency price. N(·)= standard cumulative normal distribution function. In 1983, Garman and Kohlhagen[7] devised a formula, which adjusted the Black-Scholes model to accommodate the special features of foreign currency option valuation. The Garman-Kohlhagen model is similar to the Black-Scholes model (1973) with continuous dividends.

The Black-Scholes model applies to non-dividend paying stocks. The interest rate is the forward premium because stocks must be priced competitively. This approach treats foreign currencies as assets that pay continuously compounded dividends equal to the foreign interest rates. The value of a foreign currency option is determined by domestic and foreign interest rates, the underlying spot currency price, the time to maturity of the option, the exercise price of the option and the volatility of exchange rates (volatility refers to standard deviation or variance of the proportional changes in foreign currency prices).

All the variables except the volatility of the exchange rates are known at the time of the option's initiation. The difference arises because the Black-Scholes model assumes that stocks do not pay dividends and thus there must be a forward premium to reflect the opportunity cost of holding the stock rather than a risk-free bond, i. e., the interest rate. In the case of foreign currency the forward price is related to the ratio of the prices of riskless bonds denominated in the two currencies.

The only difference between the two models is that here the continuous dividend paying stock is replaced by the current price of the stock in the Blacks-Scholes model. In other words, the Garman-Kohlhagen model includes the interest rate spread ($r_d - r_F$). Also the foreign interest rate (r_F) enters separately. As in the Black-Scholes model, Garman and Kohlhagen develop a theoretical model for estimating the price of European option.

The Black-Scholes option pricing model produces arbitrage free prices which buyers and sellers can agree upon because both can obtain an arbitrage zero net profit. This is provided that options are traded at arbitrage-free prices and are hedged with appropriate long and short positions in the underlying assets. The only other basic requirements are that those hedges be rebalanced on an ongoing basis and that cash flows be financed by borrowing at the risk-free interest rate

[7] See Garman and Kohlhagen (1983).

and invested at the risk-free rate.[8]

2. 1. 2 Estimation of Implied Volatility

The implied volatilities of the spot exchange rate from option prices contains information that is useful for forecasting future exchange rate volatility. The implied volatility is the unique volatility that equates the model price of an option with an observed market price of the option - given market observations on the spot rate and the domestic and foreign interest rates, and given the strike price and term-to-maturity of the option. It can be viewed as the current best consensus estimate by the market participants regarding future volatility of the spot exchange rate over the time to expiration, because it is calculated from actual option prices, it should reflect all available market information. Since no explicit equation for standard deviation can be obtained from our model, numerical search procedures must be used.

First, an initial guess for standard deviation is made, and substituted into Garman-Kohlhagen equation. If the computed option price is too large (small), then a smaller (larger) value for standard deviation will be used. Different options on the same underlying foreign currency may result in different implied volatilities. In the empirical study here, we obtain the daily implied parameters estimates for a foreign currency by minimizing the sum of squared deviations between market prices and model prices of the option trades on the same currency of the previous day.

From the option valuation formula, Harvey and Whaley (1992a) specify the following model:

$$y = g(S, X, T-t, r_d, r_f, \sigma) \tag{2}$$

where, y = price of option, X = exercise price of option, S = spot exchange rate, $T-t$ = time remaining to option expiration, r_d = domestic interest rate, r_f = foreign interest rate, σ = volatility of spot price.

Since all the variables, except for the volatility variable, are known at the time of option valuation, we can compute the implied volatility by inverting the formula (2) to obtain:

$$\sigma = g^{-1}(y, S, X, T-t, r_d, r_f), \tag{3}$$

We can solve for the implied exchange rate volatility that equates the theoretical value, given the current price of the option, the spot exchange rate, etc.

Thus, we consider the implied exchange rate volatility can be obtained from

[8] See Black-Scholes(1973).

the following equation:

$$y_i = g(S_i, X_i, (T-t)_i, r_{di}, r_{fi}, \sigma_i) + \varepsilon_i , \tag{4}$$

where y_i denotes the observed market price of the i-th at-and near-the money option and ε_i is the error term. Equation (4) shows that model price of the currency options price can be computed using the spot exchange rate, the exercise price of the option, the time remaining to option expiration, the domestic interest rate, the foreign interest rate and the volatility of the option. The implied volatility is the volatility that equates the model price and the observed market price. We can calculate implied volatility with an iterative procedure using a Newton- Raphson approximation technique.

2. 1. 3 Empirical Model and Estimation Procedures

We use GMM method with weighting matrix estimated by Newey and West (1988) to examine the effect of intervention on the change in the implied volatility of the exchange rate. The implied volatility reveals conditional heteroscedasticity and serial correlation error. Thus we use the weighting matrix. In carrying out GMM estimation, we employ the weighting matrix as the inverse of asymptotic covariance matrix suggested by Newey and West (1988).[9] The merit of the Newey-West procedure is to produce consistent covariance matrix for the estimated parameters, under the condition that residuals are conditionally heteroscedastic and serially correlated. Following Bonser-Neal and Tanner (1995), we use the following forms of equation:

$$\begin{aligned}\ln(ISD(\$/j)_t / ISD(\$/j)_{t-1}) = {} & \beta_0 + \beta_1 US_{j,t-1} + \beta_2 BJI_{j,t} + \beta_3 DAY_t + \\ & \sum_{i=1}^{6} \gamma_i MACROD_{it} + \sum_{i=1}^{6} \delta_k \mid MACROS_{kt} \mid + SP_t^2 + \\ & \ln(ISD(\$/j)_{t-1} / ISD(\$/j)_{t-2}) + \varepsilon_t \end{aligned} \tag{5}$$

where,
$ISD(\$/j)_t$ = estimate of implied volatility of the \$ against j on day t. $US_{j,t-1}$ = 1 if U. S. intervene against currency j in \$ millions on day t-1. $BJI_{j,t}$ = Intervention of reported or "perceived" Bundesbank or Bank of Japan on day t, which equals 1 if WSJ reported country j intervenes and 0 elsewhere. DAY_t = 1 if day t is a Monday or if day t is the first trading day after market holiday. $MACROD_{it}$ = 1 if a macroeconomic value is announced on day and 0 else, for i = 1 to 6. The macroeconomic variables are the money supply (M1), the trade de-

[9] SAS program is used to find weighted matrix.

ficit, industrial production, the producer price index (PPI), the consumer price index (CPI), and the rate of unemployment. Note that only the money supply variable is dated at t-1. This is because the money supply announcement is made regularly at 4:30 p. m. after the close of the Philadelphia Stock Exchange. $MACROS_{kt}$ = the surprise component of each macroeconomic announcement k, for k =1 to 6, measured by the difference between the announced value and the median of forecast from the Money Market Service. SP_t^2 = change in S&P 500 volatility, the first difference of the squared percent change in the S&P 500 index, measured as the first difference of the square of the log of a ratio of the S&P 500 index at 10:00 a. m. on day t-1. ε_t = error term.

Similar to Bonser-Neal and Tanner (1995), we include Federal Reserve intervention at time t-1, and we use foreign intervention at t in equation (5). We use a holiday/weekend dummy variable to detect whether the changes in implied volatility are different after a holiday/weekend. We also use two kinds of macroeconomic announcements. First, dummy variables equal to 1 on the day a particular series is announced, and 0 elsewhere. Second, the absolute value of the surprise component of each announcement is included to examine the difference between the announced value and the expected value. Because we want to measure whether the magnitude of the surprise, rather than its direction, has an effect on the change in implied volatility of DM and YEN exchange rates.

We also include the first difference of the squared percent change in the S&P 500 index to reflect the effects of economic and political events on market volatility, which are excluded in the news variables. Because, the S&P 500 index is a value-weighted arithmetic mean of the market value of the component stocks. It consists of 500 stocks, with the price of each stock weighted according to its market value. In this sense, it reflects the aggregate value of the underlying securities and can be viewed as hypothetical portfolios that consist of the entire market value of each security that is included in the index. So, it should capture the overall price movements of a broad range of industry groupings.

Lastly, the lagged value of the implied volatility is used to control for the potential simultaneity bias. If central bank intervention is related with lagged implied volatility of each exchange rate, the value of the intervention coefficients will measure the effect of the intervention conditional on the level of recent volatility.

Ⅲ. EMPIRICAL TESTS AND RESULTS

We will examine the effects of central bank intervention on the changes of implied volatilities of DM and YEN exchange rates using a GMM estimator. By focusing on the changes of the implied volatilities, we can detect the market's reaction to information about central bank intervention. By focusing in the changes of the volatilities, rather than their levels, we can isolate the reaction of the market to information the central bank intervention. We include the six macro announcement variables, their surprise components, and the S&P 500 index.

Table 1 presents the results of estimated equation (5) for the daily changes in the implied volatilities of DM and YEN exchange rates during the post- Louvre period. Our results show that the effects of the Federal Reserve, and Bank of Japan interventions on the change in implied volatilities of DM and YEN exchange rates are positive and significant. They indicate that the intervention policies increased the implied volatilities of the DM or the YEN exchange rates in the currency options market during the post-Louvre period. In contrast to Bonser-Neal and Tanner (1995), however, our results also show a positive and statistically significant effect of the Bundesbank intervention during the same period.

The holiday/weekend effects are significant and positive in the both cases. indicating that the changes in implied volatilities of the DM and the YEN exchange rates increased after holidays and weekends. Several macroeconomic variables are significant. Our results also show how the macroeconomic announcements affect volatility changes. The trade deficit and the CPI announcement dummies have negative and significant effects on the change in the implied volatility of DM exchange rates. Market participants may expect that the trade deficit announcement will lead to central bank intervention to alter the value of a dollar, or it may simply indicate that the "news" reduces speculation about what the "news" was going to be. Also, while the first difference of the squared percent change in the S&P 500 index has a positive and significant effect, the lagged implied volatility has a significant and negative effect on both cases.

Since the S&P 500 index reflects the average market value of each security that is included in the index, the significant and positive associations indicate that increases in U. S. stock market volatility raises the changes in the implied volatility of exchange rate for both currencies during the post-Louvre period. In contrast to news variables, the S&P 500 reflects the influences of economic and political events on market volatility.

Except for the effects of the Bundesbank, our results are generally similar to those of Bonser-Neal and Tanner (1995).[10] If market participants are uncertain about the effectiveness of intervention policy about the ability or willingness of the central bank intervention to maintain the exchange rate within certain target zones, then their intervention could result in exchange market instability. For example, it might increase uncertainty or cause market participants to speculate

[10] For the Bundesbank intervention, t-statistics of our result and that of Bonser-Neal and Tanner (1995) are 2.64 and 0.12 respectively. We, therefore, can explain the different result that stem from using a different options pricing model and a different GMM estimator, i. e., the Garman-Kohlhagen model and the Newey-West estimator.

[Table 1] GMM: Regressions of Daily Log Changes in the Implied Volatilities of the DM and the YEN Exchange Rates.

$$\ln(ISD(\$/j)_t / ISD(\$/j)_{t-1}) = \beta_0 + \beta_1 US_{j,t-1} + \beta_2 BJI_{j,t} + \beta_3 DAY_t + \sum_{i=1}^{6} \gamma_i MACROD_{it} + \sum_{k=1}^{6} \delta_k \mid MACROS_{kt} \mid + SP_t^2 + \ln(ISD(\$/j)_{t-1} / ISD(\$/j)_{t-2}) + \varepsilon_t$$

(February 23, 1987 - December 31, 1989, n=665)

Variables	DM	YEN
Intercept	6.3123**	5.6391**
	(1.5911)	(2.0323)
Fed Intervention Dummy	0.1743**	0.0173**
	(0.056)	(0.006)
Bundesbank Dummy	0.0369**	–
	(0.014)	–
Bank of Japan Dummy	–	3.2834**
	–	(1.109)
Holiday/Weekend Dummy	0.5741**	0.2438**
	(0.215)	(0.089)
M1 Annou.Dummy	0.0125	1.8215
	(0.032)	(2.248)
M1 Surprise	−0.7123	−0.2952
	(0.561)	(1.065)
Trad. Def. Annou. Dummy	−3.8417**	−6.2285**
	(1.329)	(1.561)
Trad. Def. Surprise	2.3541	3.2341
	(3.018)	(3.515)
Ind. Prod. Annou. Dummy	−1.3016	−0.9234
	(0.986)	(1.884)
Ind. Prod. Surprise	3.3729	−3.4544
	(8.648)	(3.796)
PPI Annou. Dummy	−1.7639	−1.2948
	(1.296)	(1.599)
PPI Surprise	4.8729	3.4871
	(3.556)	(2.746)
CPI Annou. Dummy	−3.4651*	3.3718
	(1.863)	(2.574)
CPI Surprise	17.6143	−29.1324
	(11.58)	(23.879)
Unemp. Annou. Dummy	−0.7256	−0.5428
	(0.490)	(1.392)

Variables	DM	YEN
Unemp. Surprise	−3.4758	−5.2645
	(4.697)	(7.415)
Change in S&P 500 Vol.	6.2674**	7.3654**
	(2.096)	(2.123)
Lagged Implied Vol.	−3.4253**	−4.6785**
	(0.497)	(0.6761)
Adjusted R^2	0.124	0.132

Notes: standard errors in parentheses, * = significant at 10% level, ** = significant at 5% level.The dependent variables, the changes of implied volatilities of DM and YEN exchange rates are from (ISD_t/ISD_{t-1}), ISD_t shows implied volatility of exchange rate at t. All independent values are used in absolute values, and all are multiplied by 100 except the lagged implied volatility and S&P 500 volatility. The Federal Reserve, Bundesbank and Bank of Japan intervention equal one if they intervene, and 0 else. Holiday/Weekend dummy variable equals one if observation falls on a Monday or the day after a holiday. For each macroeconomic variable, we use two kinds of variables: one is a dummy variable, the other is a surprise component. In a dummy variable, we use one if the value is announced, zero else; and a surprise component (announced value - median of the expected value by MMS).

against the central banks. Thus, as shown from our results, the Federal Reserve, Bundesbank and Bank of Japan interventions appear to cause the market participants to revise upward their expectations of exchange rate volatilities. This is reflected in the increased change in the implied volatilities of the DM and YEN exchange rates.

IV. SUMMARY AND CONCLUSIONS

The empirical results show that the effects of the Federal Reserve, Bundesbank and the Bank of Japan's intervention policies against the DM and the YEN exchange rates in the options market were significant and positive throughout our sample period, i. e., the intervention policies increased the changes in the implied volatilities of both exchange rates. These results generally support those of Bonser-Neal and Tanner (1995) even though we use the Garman-Kohlhagen currency options price model to find implied volatilities of the DM and the YEN exchange rates. If market participants were uncertain about the effectiveness of intervention policy about the ability or willingness of the central bank intervention to maintain the exchange rate within certain target zones through our sample period. Because the intervention increased uncertainty or cause market participants to speculate against the central bank. As Krugman (1991) stated, we can find that a possible reason for the failure of their interventions to calm the volatilities of the both exchange rates may lie in their failure to establish exchange-rate-target zones during the post-Louvre period.

APPENDIX

1. Spot Exchange Rate Data

The exchange rate data used in the empirical tests are compiled from the Federal Reserve Bank of New York. Our data consist of daily closing bid prices of two major currencies: Deutsche Mark (DM) and Japanese Yen (YEN). We use 665 daily observations, from February 23, 1987 to December 31, 1989. The rates of change are calculated by taking the logarithmic differences between successive trading days.

2. Central Banks Intervention Data

Until recently, most central banks have not routinely made daily intervention data available to the public. At the Versailles Summit in 1982, the Group of Seven (G-7) central banks agreed to share daily intervention data with each other as part of a multicountry study of intervention policy. The US Treasury has allowed the Board of Governors of the Federal Reserve System to make its daily intervention data publicly available with a minimum of a one-year lag. The intervention data were provided to us by the Board of Governors of the Federal Reserve System. However, Bundesbank and Bank of Japan actual data are unavailable, we use reported data from the Wall Street Journal. And, since we want to examine the effects of the three central bank interventions on the volatilities of the DM and YEN exchange rates during the post-Louvre Accord period, we use the data for the time period from February 23, 1987 to December 31, 1989. To focus the intervention effects during the post-Louvre period, we select above sample period.

The intervention data series measures consolidated daily official foreign exchange transactions in millions of dollars at current market values. Positive values denote purchases of dollars, and negative values denote official dollar sales. The central bank intervention data distinguish between interventions against the DM and the YEN and exclude so-called "passive" intervention operations. Passive interventions are Fed purchases and sales of foreign currency with customers who would otherwise have dealt with market agents. Table 3-1 shows central bank intervention data during our sample period.

3. Currency Options Data

The data utilized in this dissertation are based on daily transactions data from the PHLX for the time period from February 23, 1987 to December 31, 1989. Since the DM and the YEN are the most actively traded in the foreign currency option trading market, we select their call options price data. The expiration months for these contracts are March, June, September and December. In addition, the exchange added contracts expiring in the nearest two months surrounding these quarter months. These are transactions on the spot exchange rate. Since these options are both written and traded on an organized exchange, they have standard contract sizes. Our study sample is restricted to near at-the-money call options with 7 to 100 days to maturity. Near at-the-money options are used because they tend to be the most sensitive to changes in volatility, and hence the most informative about volatility. We use prices on options with 7 to 100 days to maturity because model-derived options prices tend to be less biased over this period.

Since the PHLX data base does not provide data on interest rates, daily domestic and foreign interest data have been obtained from the Solomon Brothers Inc.[11] We use Euro-currency bid rates (deposit rates) and German and Japanese

[Table 3-2] Central Bank Intervention (daily) Data
Sample period: February 23, 1987 - December 31, 1989, obs=665.

Central Banks	Against the $/DM	Against the $/YEN
Federal Reserve*	145	131
Bundesbank**	97	–
Bank of Japan***	–	114

* = Panel reports the number of days the Federal Reserve(actually) intervened in each currency. Source: Board of Governors, Federal Reserve.
** = Panel reports the number of days the Bundesbank intervened each exchange rate. The data show Wall Street Journal reports. Source: The Wall Street Journal.
*** = Panel reports the number of days the Bank of Japan intervened in each exchange rate. The data show Wall Street Journal reports. Source: The Wall Street Journal.

maturity dates, and predetermined exercise prices.[12]

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[11] I would like to thank Mr. Robert DeGennaro at Solomon Brothers Inc for kindly providing the data.

[12] 1. The exercise price intervals are .01 cent for the Yen and 1 cent for the Deutsche Mark. 2. Expiration months are March, June, September, and December, plus two additional near-term months. 3. The expiration date is the Saturday before the third Wednesday of the month.

annualized interest rates. We use the data for maturities of 7 days, 1, and 3 months.[13] Call options have been used for the Deutsche Mark, and Japanese Yen, because the interest rates on these currencies were lower than the U. S. interest rates during the sample period, and it would not have been optimal to exercise these calls early.

4. Macroeconomic Data

We use two kinds of U. S. macroeconomic data to control for changes in macroeconomic conditions.[14] We use announcement data and the surprise component for six variables: the weekly change in the money supply M1 in billions of dollars, the monthly merchandise trade balance in billions of dollars, the monthly percent change in industrial production, the monthly percent change in the consumer price index, the monthly percent change in the producer price index, and the monthly unemployment rate. Estimates of the surprise component of the macroeconomic announcements are computed by taking the difference between the announced macroeconomic value and the median forecast of the market participants surveyed by the Money Market Services, Inc., of San Francisco. We also include the first difference of the squared percent change in the S&P 500 index.

[13] Federal Reserve releases H. 15 Statistical Release, Selected Interest Rates.

[14] I am grateful to Dr. Bonser-Neal for supplying data and article.

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