Working Paper 9009

INTERVENTION AND THE FOREIGN EXCHANGE RISK PREMIUM: AN EMPIRICAL INVESTIGATION OF DAILY EFFECTS

by Owen F. Humpage and William P. Osterberg

Owen F. Humpage is an economic advisor and William P. Osterberg is an economist at the Federal Reserve Bank of Cleveland. Kyle Fleming provided able research assistance. The authors also gratefully acknowledge the technical assistance of Ralph Day.

August 1990

Abstract

Currency markets have witnessed a sharp increase in government intervention since 1985. Many observers believe that this intervention promoted the dollar's depreciation between 1985 and early 1987, and that intervention has since helped to stabilize dollar exchange rates. This paper tests for a systematic effect of daily dollar intervention on exchange rate risk premia. We test for both portfolio balance effects and signaling influences by using daily data on central bank intervention (in dollars) against both the yen and the West German mark. Following work by Dominguez (1989) and Loopesko (1984), we measure the daily risk premium in terms of the deviation from uncovered interest parity. However, we follow other empirical analyses of exchange rates and allow for generalized conditional autoregressive heteroscedasticity (GARCH). Some evidence is found for both the portfolio balance and signaling channels.

I. Introduction

The recent emphasis on foreign exchange intervention by several large industrialized nations has renewed an interest in the study of channels through which intervention may operate. Some research suggests that intervention may be responsible for the failure of exchange market efficiency models.

From a policy standpoint, if intervention has an impact on exchange rates, then the channel of its influence must be identified in order to determine whether it is an independent policy tool. For this reason, most studies focus on sterilized intervention, which by definition does not affect the monetary base. Sterilized intervention may operate through either the portfolio balance or signaling channel.

Most empirical studies have found little support for the portfolio balance channel. Evidence of a signaling role is somewhat stronger; however, disentangling the two effects is difficult.

This paper uses confidential daily data on G-3 central bank intervention to test for the presence of both portfolio balance and signaling effects of intervention on exchange rate risk premia. Use of high-frequency daily data allows us to capture the relationships among intervention, volatility, and excess returns.

The existence of a risk premium is one possible explanation for the poor out-of-sample forecasting performance of exchange rate models. Variances of exchange rates seem to show persistence, with distinct periods of low and high volatility. Various researchers have suggested that policy shifts may be related to volatility in asset prices. Thus, it may be useful to think of the impact of intervention as operating specifically through a risk premium.

Unfortunately, there is no consensus on how to model risk in foreign exchange. A widely used approach is to analyze the relationship between forward rates and spot rates. Hodrick (1989), for example, relates the forward premium to conditional means and variances of market fundamentals. One disadvantage of approaches that relate risk premia to fundamentals is that they do not permit testing with high-frequency data. However, a method that can be applied to daily analyses of intervention is to analyze the measure of realized excess returns suggested by the uncovered interest parity (UIP) condition. Two previous studies (Loopesko [1984] and Dominguez [1989]) have taken this approach. This paper differs by using more recent data and modeling the conditional variance of the excess returns.

We take advantage of recent advances in modeling conditional variances in asset returns (generalized autoregressive conditional heteroscedasticity [GARCH]), particularly as applied to exchange rates. Baillie and Bollerslev's 1989 study is one of many to find evidence for GARCH in exchange rates. To allow for the possibility that the conditional variance of the excess return influences its mean (GARCH-M), and that intervention influences the conditional variance, we utilize a variant of GARCH-M that allows the error term to have a conditional student-*t* distribution. In previous applications to exchange rate data, the student-*t* distribution has explained leptokurtosis (Baillie and Bollerslev).

Our analysis confirms the existence of portfolio balance and signaling channels, but differs from other studies in regard to which countries' operations had significant impacts. Although evidence of GARCH is present, the conditional variance does not influence the conditional mean (no GARCH-M). In addition, we find evidence of day-of-the-week effects.

II. Related Literature

Theory: Channels of Influence for Intervention

Theory has focused on sterilized intervention for two reasons.[1] First, the effects of unsterilized intervention may be indistinguishable from those of monetary policy. Second, most large industrialized nations claim that intervention is sterilized.

Most analyses of intervention utilize the portfolio balance approach (Branson and Henderson [1985]). With risk-averse investors and imperfect substitutability of assets of differing currencies, shifts in the relative supplies of assets may induce changes in rates of return via the exchange rate. However, under Ricardian equivalence, sterilized intervention would have no impact, even with imperfect substitutability (Backus and Kehoe [1988]).

The other channel through which intervention may operate is signaling, or the provision of new information to the market (Obstfeld [1989] and Dominguez [1989]). Intervention can provide an effective and credible signal about future monetary policy if 1) the central bank has inside information and the incentive to reveal it truthfully and 2) the market has the ability to determine the credibility of that information. Intervention may be preferable to other signals because it does not require the central bank to change the monetary base. On the other hand, this may make it easier to renege on the implied policy. The fact that the central bank puts its own money on the line by intervening has been cited by some as a reason why intervention may have credibility. If intervention operates through a signaling channel, then coordination may either strengthen its signal, or it may give some the incentive to "free ride," if such actions are undetectable by the market.

Evidence

While most investigations of the portfolio balance channel conclude that changes in the currency denomination of bond holdings do not influence exchange rates (see Weber [1986] for a survey), Danker et al. (1984), Loopesko (1984), Johnson (1988), and Ghosh (1989) find evidence supportive of such a channel. However, even if changes in the relative stocks do influence exchange rates, intervention still may have no meaningful impact, since the volume of sterilized intervention is small relative to the total stock of assets.

Evidence for a signaling channel is somewhat more consistent. Dominguez (1988) finds that, between 1977 and 1981, the relationship between intervention and money-supply surprises is consistent with the idea that intervention conveys information about future monetary policy. The response of exchange rates to intervention suggests that whether the market bets for or against intervention depends on the central bank's credibility in conveying such information. Using daily data, Humpage (1988) finds evidence that initial intervention has an effect on exchange rates, but subsequent intervention does not. Dominguez (1989) looks at the impact of official sterilized intervention and coordination from 1985 to 1987, and attempts to distinguish longer-term influences by using one-month and three-month interest and exchange rates. Results indicate that coordinated intervention may have a longer-term influence than unilateral intervention, the impact of which was less consistent. On the other hand, Humpage (1984) finds that U.S. monetary authorities react to smooth, unanticipated exchange rate movements, but notes no evidence of an expectations effect. Dominguez and Frankel (1990) attempt to disentangle portfolio balance from expectation influences through the use of exchange rate expectations data and newspaper accounts of intervention. They find evidence for both effects.

Loopesko (1984) and Dominguez (1989), the two studies that take the approach closest to that of this paper, use the UIP condition to test the impact of daily intervention. Loopesko examines the joint hypothesis of perfect asset substitutability and exchange market efficiency using daily data from 1975 to 1981. Cumulative central bank intervention that could have been known to market participants is the independent variable used to test for a portfolio balance effect. Lagged values of the realized profits and exchange rate are included to test for market efficiency. Although the joint hypothesis is resoundingly rejected, identification of the influence of the independent variables is clouded by the possibility that variables may have been omitted, or that not all of the measured intervention has been observed.

III. Risk Premia in Exchange Rates

There is no consensus as to the appropriate theoretical framework for exchange rate risk premia. Lucas's (1982) intertemporal dynamic two-country model implies that risk premia should be related to preferences and to the stochastic behavior of the driving processes, such as monetary policy. The intertemporal capital asset pricing model (Engel and Rodrigues [1987], Giovannini and Jorion [1989], and Mark [1988]) suggests that risk premia should be related to covariances among asset returns. The consumption-based capital asset pricing model (Hodrick [1989], Cumby [1988]) has specific implications for covariation between asset returns and intertemporal marginal rates of substitution in utility. Option pricing theory implies that risk premia are imbedded in foreign currency options prices (Lyons [1988], McCurdy and Morgan [1988]). Tests of all of these approaches have had mixed results. Hodrick (1987) and Baillie and McMahon (1989) provide excellent overviews of this literature.

Evidence favoring the existence of a risk premium in foreign exchange rates is indirect. Violation of the UIP condition, rejection of unbiasedness in the forward market, and poor out-of-sample forecasting performance of log-linear models that rely on first moments suggest that a risk premium may exist. However, most tests of UIP or of the relationship between forward and future spot rates are joint examinations of market efficiency, perfect substitutability, and capital mobility. Nonetheless, evidence of conditional heteroscedasticity in exchange rates naturally leads to attempts to explain time variation in the conditional variance of exchange rates.

Many of the theoretical approaches mentioned above imply that the conditional variance of exchange rates should be related to time-varying conditional covariances that involve exogenous processes such as money or output. However, testing these theories would require using data of no greater than monthly frequency. As Baillie and Bollerslev (1989) point out, evidence of time variation in conditional variance is weaker with such data.

Most efforts to model the conditional variances of exchange rates utilize ARCH (autoregressive conditional heteroscedasticity) or its variants (GARCH, GARCH-M). ARCH allows for conditional normality combined with a leptkurtic, symmetric unconditional distribution consistent with the typical fat-tailed nature of asset return data. Baillie and Bollerslev find that a version of GARCH in which the conditional distribution is student-t successfully models heteroscedasticity in the first-difference of the logarithm of daily exchange rates. Hsieh (1989) confirms the ability of ARCH or GARCH, in combination with various assumptions regarding nonnormality, to remove heteroscedasticity from similar data. Both Baillie and Bollerslev and Hsieh (1988) find day-of-the-week effects in exchange rate data.

The limitations of ARCH as a vehicle for explaining conditional variance are pointed out by Pagan and Hong (1988), Nelson (1987), and others. Hodrick (1987, p. 110) argues that ARCH may be inappropriate for analyzing volatility in exchange rates. If high-risk premia are rooted in policy uncertainty, then clarification by policymakers should reduce them. However, ARCH implies persistence in conditional variance, so the implied risk premia would only be reduced after a period of lower ex-post volatility. The role of policy regime shifts in explaining exchange market volatility is explored empirically by Lastrapes (1989).

IV. Interest Parity and Excess Return

We use the UIP condition to generate our measure of the exchange rate risk premium. An alternative would be to use the covered interest parity condition, which involves forward contracts. However, forward contracts are intended for delivery at least one month in the future, which, with daily data, would entail a loss of degrees of freedom in order to account for serially correlated errors induced by overlapping forecast intervals. UIP suggests utilizing equation (1).

(1) $RET_t = (1+R_t) - (1+R_t^*)(E[S_{t+1}]/S_t)$,

where

R_t = domestic interest rate,
R_t^* = foreign interest rate,
S_t = exchange rate (foreign currency price of U.S. dollars), and
RET_t = excess return.

Here, the investor does not cover the transaction by selling forward, but instead forms expectations of the spot rate ($E[S_{t+1}]$ for a one-day investment), which is uncertain at the time of the transaction.

We utilize daily data on interest rates, exchange rates, and intervention. Timing conventions in the foreign exchange markets require the buying and selling of currency to be completed prior to the investment. Consider an investor who places funds overnight. This investor buys West German marks on day t-2 for delivery on day t. On day t-1, he sells the marks for dollars that are to be delivered on day t+1. On day t, his marks are collected and invested overnight. On day t+1, he receives his marks, which he had previously contracted to sell. These considerations, together with the assumption that $E[S_{t+1}] = S_{t+1}$, imply equation (2).

(2) $RET_t = (1+R_t) - (1+R_t^*)(S_{t-2}/S_{t-1}) = RP_t + FE_t$,

where the excess return has been decomposed into a risk premium (RP) and a forecast error (FE). Since we utilize S_{t+1} instead of its expectation, an MA(1) term is introduced into FE_t. A regression of RET_t on variables that would be in the investor's information set at transaction time provides a joint test of informational efficiency and absence of a risk premium. Hence, if our measure of intervention captures its influence on portfolio balance at t-3 and explains RET_t, we would have evidence of an influence on risk premia if this market were informationally efficient.

We introduce intervention in two forms. To test for its influence through the portfolio balance channel, the total of the two countries' cumulative intervention is entered at t-3. If this measure captures a portfolio balance effect, then the identity of the countries should be immaterial. To examine this, each country's cumulative total is entered separately, as well. As indicated above, this is a joint test of efficiency and the existence of a risk premium. In addition, in the absence of a portfolio balance channel, this test may indicate a signaling role for intervention. To further test for a signaling effect, we distinguish between coordinated and unilateral intervention at t-3.

V. An Empirical Model

A substantial body of literature suggests that a martingale process aptly describes movements in exchange rates, and that the variances of the first differences of exchange rates are heteroscedastic. Here, we model the forecast error with the GARCH procedure used by Baillie and Bollerslev (1989). The residuals from the conditional mean equation for RET_t are assumed to be generated by a conditional student-*t* distribution, and the conditional variance of the residuals, h_t, is modeled as an ARMA process.

(3) $Y_t = X_t\underline{b} + \pi h_t^p + u_t$

(4) $u_t = e_t - \theta e_{t-1}$

(5) $e_t | I_{t-1} \sim t(0, h_t, v)$

(6) $h_t = \Omega + \alpha\, e_{t-1}^2 + \beta\, h_{t-1} + w_t$

In equation (3), Y_t is the measured excess return and X_t is the vector of explanatory variables, which includes intervention, an intercept, four day-of-the-week dummies, and dummies for missing data and vacation days. In equation (4), the error u_t is allowed to follow an MA(1) process. The term πh_t^p allows for the conditional variance (p=1) or the conditional standard deviation (p=.5) to influence the excess return. Although we do not present a theoretical model for this effect, it is implied by models such as that in Hodrick (1989).

Equation (5) indicates that the distribution of the e_t conditional on the information set I_{t-1} is student-*t*, with mean zero, variance h_t, and distributional parameter *v*. If *v* exceeds 30, this distribution is approximately normal. Equation (6) shows that we utilize a GARCH(1,1) parameterization, with an intercept.

Preliminary Tests and Procedures

A standard ARMA analysis of RET_t did not help us to distinguish between AR(1) and MA(1) representations. Since overlapping forecast intervals suggest an MA(1) form, that is the one with which we proceed. Augmented Dickey-Fuller tests reject the hypothesis of a unit root in Y_t.

In order to examine the sensitivity of our results on the significance of intervention on excess returns, we omit the daily dummies, the MA(1) term, and the ARCH-in-mean term (h_t or $h_t^{.5}$) from the mean equation. The extent to which the residuals are nonwhite is indicated by the reported Q statistics (Q[15] indicates that 15 lags were utilized). $Q/(h_t^{.5})$ adjusts the usual Q statistic for heteroscedasticity, and Q^2 is the standard Q statistic for the squared residuals, which may indicate ARCH effects. It, too, is adjusted for heteroscedasticity, and then reported as Q^2/h_t. The parameter v indicates the extent to which the distribution deviates from normality. The sample measure of skewness aids in indicating the success of our distributional assumptions in modeling the conditional variance. Finally, we report the sample analogue to kurtosis, $3(v-2)/(v-4)$, where appropriate.

Data

The sample period is August 3, 1984 to February 19, 1990, and there are 1,770 daily observations, excluding lags. We obtained the exchange rate and interest rate data from the Paris market through DRIFACS PLUS (1988). The ultimate source is Credit Lyonnais, Paris. Yen-dollar and mark-dollar exchange rates are constructed as cross-rates for each currency quoted against the French franc. The exchange rate data are averages of bid and ask quotes as of 2:00 p.m. in Paris. Interest rates are overnight Eurocurrency deposit rates, quoted on a 360-day basis, as of 9:30 a.m.; they are converted to a daily basis. The market chosen is the only one in which we found overnight Euroyen deposit rates.

Intervention data are daily net purchases of dollars by the United States, West Germany, and Japan, provided by the Board of Governors of the Federal Reserve System. Since the data are measured in dollars, we avoid the need to construct dollar measures of intervention using the exchange rate, which would imbed simultaneity into our analysis. Over the period investigated, virtually all U.S. intervention was against the mark or yen. The single exception was a purchase of $16.4 million equivalent British pounds in

February 1985 (see Cross [1985, p. 58]). We include West German and Japanese intervention, but not intervention by other large central banks, which tend to focus intervention on their own currency's exchange rate rather than on the yen-dollar or mark-dollar rate. Moreover, their currency's relationship against the dollar need not be the objective of the intervention: Many participants in the European Monetary System (EMS) intervene in dollars to maintain their currencies within EMS limits. Although third-party intervention may affect the yen-dollar or the mark-dollar exchange rate, the impact is often caused by the aggregation of purchases and sales of dollars undertaken independently by many different countries.

Results

The portfolio balance channel and cumulative intervention

If the portfolio balance channel is operative, the total change in relative portfolios should be important to the investor. In Table I, we use as our intervention measure the total of U.S. and West German purchases of U.S. dollars against the mark as of date t-3. Since intervention is measured at the end of the day, this is information that investors could have had. Table I indicates that an increase in dollar purchases tends to result in significantly increased (at the 1 percent level) dollar excess returns.

In the absence of an agreed-upon theory of the determination of exchange rate risk premia, it is unclear how we should interpret the sign of the impact of intervention. However, the portfolio balance approach suggests that the excess return on dollar assets must increase in order to compensate investors for holding a greater stock of dollar assets. The positive coefficient implies that an increase in the stock of dollar assets (a negative value) is associated with a decrease in the risk premium. This is inconsistent with what the portfolio balance approach implies. The significance of the cumulative intervention measure is in agreement with Loopesko (1984), who unfortunately does not report the direction of the effect that she finds.

Of course, we cannot claim to have distinguished between a portfolio channel and the possibility that intervention has had a role in signaling new information to the market. For example, an examination of equation (2) confirms that, ceteris paribus, RET and S_{t-1} are positively correlated. The risk premia would be reflected in $E[S_{t-1}]$. However, the forecast error may be correlated with new information that intervention could provide.

In Table II, we split the total cumulative intervention measure utilized in Table I into U.S. and West German purchases. If a portfolio balance channel is operative, the identity of the purchaser should be inconsequential. Thus, we would expect both variables to be significant. Results indicate, however, that only West German purchases of dollars have a significant impact on excess returns (about 10 percent). The sign of the effects is again positive.

Tables III and IV indicate the results for the excess return of dollars over yen. There is no evidence that intervention has a significant influence.

The signaling channel and coordinated versus uncoordinated intervention

If intervention works through providing signals to the market, then it need not be cumulative, and it might be necessary to distinguish between uncoordinated and unilateral interventions; this study measures both at t-3. If intervention is coordinated (both countries intervene in the same direction), the measure is the total of the two. Unilateral intervention is nonzero only if each country intervenes in the opposite direction, or if only one country intervenes. We use a unilateral intervention variable for each country.

Results in Table V suggest that coordinated intervention had no significant impact, while unilateral West German sales of marks (purchases of dollars) decreased the excess return on dollars. These findings are in contrast to those of Dominguez (1989), who found that unilateral U.S. intervention caused a decline in dollar excess returns, but that West German unilateral intervention had no effect.

Table VI indicates that unilateral Japanese purchases of dollars decreased dollar excess returns, but that neither coordinated nor unilateral U.S. purchases had a significant effect. Dominguez found that intervention had little impact on one-day excess returns.

Specification issues

The sign and significance of the intervention measures appear robust to changes in the specification of the conditional mean equation; neither the sign nor the significance changes when we exclude dummies, the MA(1) term, or GARCH-M effects. The MA(1) term is always significant, regardless of the inclusion of the dummies or GARCH-M effects; this is consistent with the presence of overlapping forecast intervals. The significance of the Friday dummy is similar to the findings of Baillie and Bollerslev (1989). Neither the conditional variance, h_t, nor the conditional standard deviation, $h_t^{.5}$, enters significantly into the conditional mean equation. Therefore, we did not test for an influence of intervention on the conditional variance.

We parameterized the conditional variance equation as a GARCH(1,1) with an intercept. All three terms are significant. Following Baillie and Bollerslev's study of exchange rates, we assumed that the errors followed a conditional student-*t* distribution. Our estimation of the distributional parameter, *v*, indicates that the conditional errors are in fact nonnormal. At first glance, the specification appears to have removed heteroscedasticity. The Q^2/h_t statistics are low, indicating that our GARCH/student-*t* parameterization successfully adjusted for the ARCH effects indicated by the high Q^2 statistics. However, the presence of skewness (indicated by the M1 statistic) and kurtosis (indicated by the value of its sample analogue, $3[v-2]/[v-4]$) indicates that our parameterization was not totally successful. The sample analogue is not reported where the estimated value of *v* implies that it would be negative.

VI. Conclusion

Using daily data on intervention and an excess return measure from the UIP condition as proxies for the one-day risk premium in the foreign exchange market, we test for the presence of portfolio balance and signaling effects of intervention. We utilize a GARCH(1,1) parameterization of the conditional variance with an assumption of conditional student-*t* distribution, in an attempt to correctly adjust for heteroscedasticity.

Like Loopesko (1984), we find some evidence for a portfolio balance effect for the mark/U.S. dollar excess return. However, the sign of the impact is inconsistent with an increased risk premium being induced by a rise in the relative supply of dollar assets. We did not disentangle portfolio balance and signaling influences, however. In attempting to distinguish between coordinated and unilateral intervention, we find that only the latter is significant. Both West German and Japanese unilateral purchases of dollars decrease dollar excess returns. This finding is roughly consistent with the results of Dominguez (1989), who also looks at returns over longer time horizons.

Further investigation is necessary to explain the sign of the impact of the portfolio balance variables, the significance of only unilateral (not coordinated) intervention, and the presence of skewness and kurtosis.

Footnote

1. See Edison (1990) for an excellent survey and annotated bibliography of important literature on intervention.

Table I
The Portfolio Balance Channel (dollar/mark)
Influence of Lagged (t-3) Cumulative Total Intervention

Conditional mean equation					
Intercept	0.0018	0.0025	0.0018	0.0014	0.0018
	3.5185	2.2387	3.7032	3.3654	3.6062
Monday	-0.0005	-0.0005	-0.0005		-0.0005
	-0.8832	-1.0197	-0.9536		-0.9735
Wednesday	-0.0003	-0.0003	-0.0003		-0.0003
	-0.5360	-0.6027	-0.5314		-0.6191
Thursday	-0.0006	-0.0007	-0.0006		-0.0006
	-1.3899	-1.4675	-1.3177		-1.3194
Friday	-0.0011	-0.0011	-0.0011		-0.0011
	-2.1864	-2.1857	-2.2448		-2.1864
Missing	0.0007	0.0006	0.0007		0.0008
	0.5600	0.5260	0.5894		0.6760
Vacation	-0.0004	-0.0004	-0.0004		-0.0005
	-0.4918	-0.4881	-0.5334		-0.5809
Intervention	0.0005	0.0004	0.0004	0.0005	0.0005
	3.4362	3.3725	3.3928	3.5424	3.2512
$\pi(p=1)$	0.4023				
	0.1208				
$\pi(p=.5)$		-0.0859			
		-0.6100			
θ	-0.0537	-0.0540	-0.0535	-0.0536	
	-2.1027	-2.1183	-2.0985	-2.1010	
Conditional variance equation					
	-2.1027	-2.1183	-2.0985	-2.1010	
Ω	1.36E-05	1.4E-05	1.39E-05	1.40E-05	1.38E-05
	6.0900	6.1648	6.3512	6.3499	6.3257
α	0.1506	0.1505	0.1481	0.1485	0.1494
	4.9037	4.9231	4.8712	4.8467	4.8857
β	0.6294	0.6220	0.6261	0.6252	0.6274
	14.4295	14.1677	14.6917	14.5871	14.7021
1/v	0.1845	0.1829	0.1840	0.1826	0.1827
	9.9173	10.8936	37.1307	24.5413	39.0568
Diagnostics					
Log likelihood	6154.7598	6154.8867	6154.5103	6151.4225	6152.1782
Q(15)	372.4294	487.8962	437.7330	437.9254	386.3016
$Q(15)/(h^{.5})$	0.8209	1.0456	0.8962	0.8756	0.5376
$Q^2(15)$	446.1485	439.3750	440.9127	440.8378	443.7393
$Q^2(15)/h$	0.0004	0.0005	0.0004	0.0004	0.0003
M3	35.4311	35.3810	35.7495	35.8311	35.8146
3(v-2)/(v-4)	7.23	7.09	7.18	7.06	7.07

NOTE: t-statistics appear below coefficient estimates.
SOURCE: Authors' calculations.

Table II
The Portfolio Balance Channel (dollar/mark)
Influence of Lagged (t-3) Cumulative Separate Interventions

Conditional mean equation					
Intercept	-0.0020	0.0027	0.0020	0.0016	0.0020
	3.0282	2.3735	2.9065	2.6374	2.9801
Monday	-0.0006	-0.0005	-0.0005		-0.0005
	-1.1621	-0.9534	-0.8867		-0.9920
Wednesday	-0.0004	-0.0003	-0.0003		-0.0003
	-0.7546	-0.5365	-0.5292		-0.6293
Thursday	-0.0007	-0.0006	-0.0006		-0.0007
	-1.4680	-1.4013	-1.3185		-1.3971
Friday	-0.0012	-0.0011	-0.0011		-0.0011
	-2.3242	-2.1837	-2.2447		-2.2638
Missing	-0.0004	-0.0004	0.0007		0.0008
	-0.4867	-0.4937	0.5603		0.9770
Vacation	0.0007	0.0007	-0.0004		-0.0005
	-0.5860	0.5602	-0.4919		-0.5850
U.S. intervention	0.0002	0.0001	0.0001	0.0001	0.0001
	0.2566	0.2098	0.1977	0.2066	0.2066
West German	0.0006	0.0006	0.0006	0.0006	0.0006
intervention	1.7358	1.8856	1.7022	2.0025	1.6995
π(p=1)	0.3986				
	0.1240				
π(p=.5)		-0.0962			
		-0.6796			
θ	-0.0546	-0.0547	-0.0539	-0.0537	
	-2.1201	-2.1430	-2.1074	-2.1103	
Conditional variance equation					
Ω	1.33E-05	1.39E-05	1.39E-05	1.42E-05	1.38E-05
	6.1186	6.1202	6.3657	6.4075	6.3366
α	0.1540	0.1545	0.1519	0.1469	0.1503
	4.9833	4.9550	4.9067	4.8184	4.8905
β	0.6305	0.6197	0.6239	0.6221	0.6264
	14.7224	14.0529	14.6850	14.4491	14.6842
$1/v$	0.1812	0.1838	0.1837	0.1822	0.1802
	4.0599	8.3976	8.4097	8.4145	1581.9630
Diagnostics					
Log likelihood	6154.8868	6155.1145	6154.7086	6151.5867	6152.2600
Q(15)	372.6054	496.6039	437.8993	437.8705	386.1370
$Q(15)/(h^{.5})$	0.7970	0.9919	0.8667	0.8783	0.5330
$Q^2(15)$	446.2050	439.1568	440.8591	440.8066	443.7417
$Q^2(15)/h$	0.0003	0.0004	0.0004	0.0004	0.0003
M3	35.5145	35.6714	35.8364	35.8296	35.8139
$3(v-2)/(v-4)$	6.95	7.16	7.16	7.03	6.87

NOTE: t-statistics appear below coefficient estimates.
SOURCE: Authors' calculations.

Table III
The Portfolio Balance Channel (dollar/yen)
Influence of Lagged (t-3) Cumulative Total Intervention

Conditional mean equation					
Intercept	0.0007	0.0014	0.0007	0.0001	0.0007
	2.7267	2.6953	2.6707	1.0588	2.6047
Monday	-0.0003	-0.0003	-0.0003		-0.0003
	-0.7797	-0.7067	-0.7828		-0.7104
Wednesday	-0.0006	-0.0006	-0.0006		-0.0006
	-1.6449	-1.5714	-1.5831		-1.6339
Thursday	-0.0006	-0.0005	-0.0006		-0.0006
	-1.5421	-1.4465	-1.5441		-1.5153
Friday	-0.0011	-0.0011	-0.0011		-0.0011
	-3.0096	-3.0029	-2.9942		-2.9519
Missing	-0.0005	-0.0005	-0.0005		-0.0005
	-0.7703	-0.7698	-0.8711		-0.8151
Vacation	0.0002	0.0002	0.0003		0.0004
	-0.2522	0.2457	0.3704		0.4404
Intervention	0.0003	5.0E-5	3.7E-5	4.1E-5	3.7E-5
	0.7191	1.0512	0.7862	0.8648	0.6793
$\pi(p=1)$	0.1601				
	0.1111				
$\pi(p=.5)$		-0.1188			
		-1.5919			
θ	-0.0947	-0.0988	-0.0946	-0.0944	
	3.7817	-3.9202	-3.7817	-3.7684	
Conditional variance equation					
Ω	1.45E-06	1.4E-06	9.1E-06	9.3E-05	9.0E-06
	6.3526	6.4211	6.5895	6.7180	6.6508
α	0.2877	0.2975	0.2884	0.2830	0.2867
	5.5414	5.5875	5.5987	5.6369	5.6743
β	0.5877	0.5753	0.5874	0.5838	0.5868
	16.0383	15.8304	17.0844	17.0467	16.9075
1/v	0.2848	0.2847	0.2849	0.2810	0.2792
	11.6170	124.9997	12.7990	10.7990	11.6079
Diagnostics					
Log likelihood	6507.9686	6509.8855	6507.8409	6502.6060	6500.1582
Q(15)	409.7954	609.5790	475.3511	474.8559	379.6473
$Q(15)/(h^{.5})$	0.7231	1.0366	0.7688	0.7665	0.3687
$Q^2(15)$	439.7333	435.0106	436.0112	435.9465	443.9177
$Q^2(15)/h$	0.0015	0.0002	0.0002	0.0002	0.0001
M3	35.98811	35.5084	36.1330	36.1470	36.0490
3(v-2)/(v-4)	****	****	****	****	****

NOTE: t-statistics appear below coefficient estimates.
SOURCE: Authors' calculations.

Table IV
The Portfolio Balance Channel (dollar/yen)
Influence of Lagged (t-3) Cumulative Separate Interventions

Conditional mean equation					
Intercept	0.0007	0.0014	0.0007	0.0001	0.0007
	2.7366	2.6638	2.7885	1.3090	2.7408
Monday	-0.0003	-0.0003	-0.0003		-0.0003
	-0.7769	-0.6855	-0.7711		-0.7052
Wednesday	-0.0006	-0.0006	-0.0006		-0.0006
	-1.6401	-1.5242	-1.6355		-1.6972
Thursday	-0.0006	-0.0005	-0.0006		-0.0006
	-1.6117	-1.4161	-1.5338		-1.5139
Friday	-0.0011	-0.0011	-0.0011		-0.0011
	-3.0586	-2.9731	-3.0396		-2.9570
Missing	-0.0005	-0.0004	-0.0005		-0.0005
	-0.7636	-0.6525	0.8200		-0.8118
Vacation	0.0002	0.0001	0.0002		0.0004
	0.2795	0.1628	0.2521		0.4114
Intervention					
U.S.	0.0004	0.0004	0.0005	0.0004	0.0004
	0.9833	1.0321	1.0476	0.9613	0.8994
Japan	6.5E-6	2.3E-6	-9.7E-6	-5.8E-6	-3.7E-6
	0.1519	0.0966	-0.1839	-0.1351	-0.1143
$\pi(p=1)$	0.1673				
	0.1195				
$\pi(p=.5)$		-0.1194			
		-1.6042			
θ	-0.0955	-0.0987	-0.0951	-0.0949	
	-3.8104	-3.9058	-3.7978	-3.7894	
Conditional variance equation					
Ω	8.8E-6	9.3E-6	9.1E-6	9.2E-6	9.0E-6
	6.3290	6.4764	6.6286	6.6962	6.6534
α	0.2882	0.2967	0.2884	0.2832	0.2875
	5.5926	5.6300	5.6118	5.6477	5.6769
β	0.5926	0.5757	0.5849	0.5855	0.5863
	15.4580	15.8875	17.0682	17.0905	16.9105
$1/v$	0.2842	0.2828	0.2853	0.2807	0.2790
	17.8645	98.6732	400.9012	14.0640	11.5588
Diagnostics					
Log likelihood	6508.2606	6510.1696	6508.1299	6502.9196	6500.3799
Q(15)	408.3021	609.9774	475.7670	475.3897	379.6236
$Q(15)/(h^{.5})$	0.7229	1.0435	0.7682	0.7666	0.3663
$Q^2(15)$	439.9127	435.0186	435.9622	435.8892	443.9180
$Q^2(15)/h$	0.0002	0.0002	0.0002	0.0002	0.0001
M3	35.9500	35.4667	36.1338	36.1429	36.0510
$3(v-2)/(v-4)$	****	****	****	****	****

NOTE: t-statistics appear below coefficient estimates.
SOURCE: Authors' calculations.

Table V
The Signaling Channel (dollar/mark)
Coordinated vs. Uncoordinated Intervention (t-3)

Conditional mean equation					
Intercept	0.0005	0.0014	0.0005	2.76E-05	0.0005
	1.4578	1.2955	1.6016	0.2308	1.6888
Monday	-0.0005	-0.0005	-0.0005		-0.0005
	-1.0253	-0.9529	-1.0199		-0.9743
Wednesday	-0.0003	-0.0002	-0.0002		-0.0003
	-0.5348	-0.3905	-0.5293		-0.5433
Thursday	-0.0007	-0.0006	-0.0007		-0.0007
	-1.4720	-1.3345	-1.3959		-1.3225
Friday	-0.0010	-0.0010	-0.0010		-0.0010
	-2.0199	-2.0205	-2.0116		-2.0088
Missing	0.0008	0.0008	0.0008		0.0009
	0.6907	0.6595	0.6855		0.7686
Vacation	-0.0004	-0.0004	-0.0004		-0.0004
	-0.4497	-0.4480	-0.4490		-0.4923
Intervention					
Coordinated	0.0066	0.0050	0.0052	-0.0056	0.0072
	0.4986	0.3832	0.3491	0.4172	0.5267
Uncoordinated					
U.S.	0.0302	0.0256	0.0271	0.0180	0.0271
	0.2894	0.2471	0.2613	0.1691	0.2594
West German	-0.1059	-0.1053	-0.1064	-0.1103	-0.1038
	-4.2700	-4.2334	-4.2499	-4.3789	-4.0831
$\pi(p=1)$	0.4384				
	0.1233				
$\pi(p=.5)$		-0.1176			
		-0.8355			
θ	-0.0528	-0.0545	-0.0521	-0.0520	
	-2.0607	-2.1196	-2.0323	-2.0353	
Conditional variance equation					
Ω	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
	5.9951	6.0284	6.2779	6.2981	6.2388
α	0.1507	0.1542	0.1482	0.1445	0.1469
	4.9137	4.9906	4.8651	4.8105	4.8525
ß	0.6344	0.6225	0.3288	0.6278	0.6326
	14.6291	14.0192	14.7654	14.5042	14.7654
1/v	0.1841	0.1793	0.1807	0.1787	0.1799
	15.0370	19.0120	12.4364	15.1698	17.1389
Diagnostics					
Log likelihood	6155.5340	6155.9838	6155.3522	6152.5895	6153.1353
Q(15)	369.6308	516.5263	438.2506	438.2815	388.1246
$Q(15)/(h^{.5})$	0.7867	1.0072	0.8533	0.8613	0.5359
$Q^2(15)$	446.7859	439.3132	441.1274	441.0789	443.7214
$Q^2(15)/h$	0.0004	0.0005	0.0004	0.0004	0.0003
M3	355.5201	35.5931	35.8715	35.8602	35.8547
3(v-2)/(v-4)	7.19	6.80	6.91	6.76	6.85

NOTE: t-statistics appear below coefficient estimates.
SOURCE: Authors' calculations.

Table VI
The Signaling Channel (dollar/yen)
Coordinated vs. Uncoordinated Intervention (t-3)

Conditional mean equation					
Intercept	0.0007	0.0013	0.0007	0.0002	0.0007
	2.7495	2.5516	2.8189	1.6394	2.6591
Monday	-0.0003	-0.0003	-0.0003		-0.0003
	-0.7937	-0.8793	-0.8000		-0.7315
Wednesday	-0.0006	-0.0006	-0.0006		-0.0006
	-1.6331	-1.6374	-1.6317		-1.6827
Thursday	-0.0006	-0.0006	-0.0006		-0.0006
	-1.6131	-1.6320	-1.6147		-1.5166
Friday	-0.0011	-0.0011	-0.0011		-0.0011
	-2.9979	-3.0736	-2.9814		-2.9537
Missing	0.0002	0.0001	0.0002		0.0003
	0.2127	0.2077	0.2540		0.3353
Vacation	-0.0005	-0.0004	-0.0005		-0.0004
	-0.7047	-0.6559	-0.8197		-0.7603
Intervention					
Coordinated	0.0027	0.0027	0.0035	0.0020	0.0053
	0.3580	0.3685	0.4654	0.2712	0.6532
Uncoordinated					
U.S.	-0.1071	0.0027	-0.1058	-0.0923	-0.0704
	-1.2436	-1.3364	-1.2236	-1.0570	-0.8010
Japan	-0.0423	-0.0414	-0.0423	-0.0435	-0.0384
	-5.1679	-5.1840	-5.1788	-5.2701	-4.5619
$\pi(p=1)$	0.1872				
	0.1267				
$\pi(p=.5)$		-0.1000			
		-1.3434			
θ	-0.1025	-0.1053	-0.1027	-0.1030	
	-4.0998	-4.1764	-4.1040	-4.1141	
Conditional variance equation					
Ω	9.52E-06	9.75E-06	9.62E-06	9.68E-06	9.38E-06
	6.4561	6.5465	6.6802	6.7712	6.7124
α	0.2936	0.3004	0.2964	0.2927	0.2926
	5.5037	5.5251	5.5262	5.5782	5.6241
β	0.5787	0.5681	0.5749	0.5735	0.5784
	16.3688	15.9491	17.0053	17.0279	16.8462
$1/v$	0.2896	0.2882	0.2896	0.2863	0.2829
	131.2577	8.0395	67.4550	229.3853	64.6777
Diagnostics					
Log likelihood	6512.0154	6513.2921	6511.8668	6506.6690	6503.0352
Q(15)	407.0639	591.9782	483.8773	483.9574	379.2670
$Q(15)/(h^{.5})$	0.6949	0.9474	0.7423	0.7392	0.3448
$Q^2(15)$	439.8882	434.2418	435.1677	435.0301	443.9188
$Q^2(15)/h$	0.0002	0.0002	0.0002	0.0002	0.0001
M3	35.9788	35.7038	36.1795	36.1750	36.0841
$3(v-2)/(v-4)$	****	****	****	****	****

NOTE: t-statistics appear below coefficient estimates.
SOURCE: Authors' calculations.

References

Backus, D., and Kehoe, P., "On the Denomination of Government Debt: A Critique of the Portfolio Balance Approach," Working Paper No. 359, Federal Reserve Bank of Minneapolis, 1988.

Baillie, Richard T., and Bollerslev, Tim, "The Message in Daily Exchange Rates: A Conditional-Variance Tale," Journal of Business & Economic Statistics, 7 (July 1989), 297-305.

________, and McMahon, Patrick C., The Foreign Exchange Market: Theory and Econometric Evidence. Cambridge: Cambridge University Press, 1989.

Branson, W.H., and Henderson, D.W., "The Specification and the Influence of Asset Markets," in R.W. Jones and P.B. Kenen, eds., Handbook of International Economics. Amsterdam: North-Holland Publishing Company, 1985.

Cross, Sam Y., "Treasury and Federal Reserve Foreign Exchange Operations, February-July 1985 Semiannual Report," Quarterly Review, Federal Reserve Bank of New York, Autumn 1985, 50-64.

Cumby, Robert E., "Is It Risk? Explaining Deviations from Uncovered Interest Parity," Journal of Monetary Economics, 22 (September 1988), 279-299.

Danker, Deborah J., Haas, Richard A., Henderson, Dale W., Symansky, Steven A., and Tryon, Ralph W., "Small Empirical Models of Exchange Market Intervention," Staff Study No. 135, Board of Governors of the Federal Reserve System, 1984.

Dominguez, K., "The Informational Role of Official Foreign Exchange Intervention Operations," manuscript, Kennedy School of Government, Harvard University, 1988.

_________, "Market Responses to Coordinated Central Bank Intervention," Working Paper No. 3192, National Bureau of Economic Research, 1989.

_________, and Frankel, Jeffrey, "Does Foreign Exchange Intervention Matter? Disentangling the Portfolio and Expectations Effects for the Mark," Working Paper No. 3299, National Bureau of Economic Research, 1990.

Edison, Hali J., "Foreign Currency Operations: An Annotated Bibliography." International Finance Discussion Papers 380, Board of Governors of the Federal Reserve System, May 1990.

Engel, Charles M., and Rodrigues, Anthony, P., "Tests of International CAPM with Time-Varying Covariances," Working Paper No. 2303, National Bureau of Economic Research, July 1987.

Ghosh, Atish R., "Is It Signalling? Exchange Intervention and the Dollar-Deutschemark Rate," Working Paper, Princeton University, 1989.

Giovannini, Alberto, and Jorion, Philippe, "The Time Variation of Risk and Return in the Foreign Exchange and Stock Markets," Journal of Finance, 44 (June 1989), 307-325.

Hodrick, Robert J., The Empirical Evidence on the Efficiency of Forward and Futures Foreign Exchange Markets, Fundamentals of Pure and Applied Economics, No. 24, Chur, Switzerland: Harwood Academic Publishers, 1987.

________, "Risk, Uncertainty, and Exchange Rates," Journal of Monetary Economics, 23 (May 1989), 433-459.

Hsieh, David A., "The Statistical Properties of Daily Foreign Exchange Rates: 1974-1983," Journal of International Economics, 24 (February 1988), 129-145.

________, "Modeling Heteroscedasticity in Daily Foreign-Exchange Rates," Journal of Business & Economic Statistics, 7 (July 1989), 307-317.

Humpage, Owen, "Dollar Intervention and the Deutschemark-Dollar Exchange Rate: A Daily Time-Series Model," Working Paper No. 8404, Federal Reserve Bank of Cleveland, September 1984.

________, "Intervention and the Dollar's Decline," Economic Review, Federal Reserve Bank of Cleveland, Quarter 2, 1988, 2-16.

Johnson, David, "The Currency Denomination of Long-Term Debt in the Canadian Corporate Sector: An Empirical Analysis," Journal of International Money and Finance, 7 (March 1988), 77-90.

Lastrapes, William D., "Exchange Rate Volatility and U.S. Monetary Policy: An ARCH Application," Journal of Money, Credit and Banking, 21 (February 1989), 66-77.

Loopesko, Bonnie E., "Relationships among Exchange Rates, Intervention, and Interest Rates: An Empirical Investigation," Journal of International Money and Finance, 3 (December 1984), 257-277.

Lucas, Robert E., Jr., "Interest Rates and Currency Prices in a Two-Country World," Journal of Monetary Economics, 10 (November 1982), 335-360.

Lyons, Richard K., "Tests of the Foreign Exchange Risk Premium Using the Expected Second Moments Implied by Option Pricing," Journal of International Money and Finance, 7 (March 1988), 91-108.

Mark, Nelson C., "Time-Varying Betas and Risk Premia in the Pricing of Forward Foreign Exchange Contracts," Journal of Financial Economics, 22 (December 1988), 335-354.

McCurdy, T.H., and Morgan, I.G., "Testing the Martingale Hypothesis in Deutschemark Futures with Models Specifying the Form of Heteroscedasticity," Journal of Applied Econometrics, 3 (July-September 1988), 187-202.

Nelson, D.B., "Conditional Heteroscedasticity and Asset Returns: A New Approach," mimeo, Massachusetts Institute of Technology, 1987.

Obstfeld, Maurice, "The Effectiveness of Foreign-Exchange Intervention: Recent Experience," Working Paper No. 2796, National Bureau of Economic Research, 1989.

Pagan A., and Hong, Y., "Non-parametric Estimation and the Risk Premium," Working Paper No. 135, Rochester Center for Economic Research, University of Rochester, 1988.

Weber, Warren E., "Do Sterilized Interventions Affect Exchange Rates?" Quarterly Review, Federal Reserve Bank of Minneapolis, Summer 1986, 14-23.