The Temporal Pattern of Trading Rule Returns and Central Bank Intervention: Intervention Does Not Generate Technical Trading Rule Profits,

Authors	Christopher J. Neely
Working Paper Number	2000-018C
Revision Date	November 1999
Citable Link	https://doi.org/10.20955/wp.2000.018
Suggested Citation	Neely, C.J., 1999; The Temporal Pattern of Trading Rule Returns and Central Bank Intervention: Intervention Does Not Generate Technical Trading Rule Profits,, Federal Reserve Bank of St. Louis Working Paper 2000-018. URL https://doi.org/10.20955/wp.2000.018

Published In	Journal of International Economics
Publisher Link	https://doi.org/10.1016/S0022-1996(01)00163-5

The Temporal Pattern of Trading Rule Returns and Central Bank Intervention: Intervention Does Not Generate Technical Trading Rule Profits

Christopher J. Neely*

November 30, 2000

Abstract: This paper characterizes the temporal pattern of trading rule returns and official intervention for Australian, German, Swiss and U.S. data to investigate whether intervention generates technical trading rule profits. High frequency data show that abnormally high trading rule returns precede German, Swiss and U.S. intervention, disproving the hypothesis that intervention generates inefficiencies from which technical rules profit. Australian intervention precedes high trading rule returns, but trading/intervention patterns make it implausible that intervention actually generates those returns. Rather, intervention responds to exchange rate trends from which trading rules have recently profited.

* Senior Economist, Research Department
411 Locust St.
Federal Reserve Bank of St. Louis
St. Louis, MO 63102
(314) 444-8568 (o), (314) 444-8731 (f), neely@stls.frb.org

Primary Subject Code: G0 - Financial Economics
Secondary Subject Code: G14 - Information and Market Efficiency
Keywords: technical analysis, trading rules, intervention, exchange rates

---

The views expressed are those of the author and do not necessarily reflect official positions of the Federal Reserve Bank of St. Louis, or the Federal Reserve System. The author thanks the Federal Reserve Bank of New York, the Board of Governors of the Federal Reserve, the Reserve Bank of Australia, the Bundesbank, the Swiss National Bank, the Bank of England and the Reserve Bank of New Zealand for assistance in obtaining data. The author also thanks Blake LeBaron, Suk-Joong Kim, Carol Osler, Paul Weller and Jeffrey Wrase for helpful comments and Mrinalini Lhila for research assistance.

Evidence has accumulated in recent years that technical analysis—the use of past price behavior to determine trading decisions—can be useful in the foreign exchange market (Sweeney (1986), Levich and Thomas (1993), Neely, Weller and Dittmar (1997)). This finding has challenged the efficient markets hypothesis, which holds that exchange rates reflect information to the point where the potential excess returns do not exceed the transactions costs of acting (trading) on that information (Jensen (1978)).

Researchers have been less successful in explaining why excess returns accrue to technical rules to than in documenting those returns. The literature has focused on three hypotheses: 1) the return to technical trading rule strategies compensates traders for bearing risk (Kho (1996)); 2) the apparent success of technical trading can be explained by data snooping (Ready (1998), Sullivan, Timmermann and White (1999)); and 3) official intervention in foreign exchange markets generate inefficiencies from which technical rules profit.

Many authors have speculated that intervention by monetary authorities is the source of technical trading rule profitability (Friedman (1953), Dooley and Shafer (1983), Corrado and Taylor (1986), Sweeney (1986), and Kritzman (1989)). The fact that technical rules seem to be less useful in equity and commodity markets—where there is no intervention—buttressed the argument (Silber (1994)). More recently, a seminal paper by LeBaron (1999) found a remarkable correlation between daily U.S. official intervention and returns to a typical moving average rule.[1] These findings further convinced many researchers that technical trading rule returns were generated by official intervention.

Further research confirmed and extended LeBaron's (1999) results. Szakmary and Mathur (1997) found that monthly trading rule returns were correlated with changes in reserves—a proxy for official intervention. Neely (1998) reconciled LeBaron's results on the profitability of trading against U.S. intervention with Leahy's (1995) results on the positive profits of U.S. intervention. Saacke (1999) extended LeBaron's results using Bundesbank data and examined the profitability of intervention for both the U.S. and Germany. Sapp (1999) used U.S. and Bundesbank data and explored whether other macroeconomic and financial variables help explain technical trading rule profits. Other studies have looked at the effects of actual or reported intervention with higher frequency data (e.g., Goodhart and Hesse (1993), Peiers (1997), Chang and Taylor (1998), Fischer and Zurlinden (1999), and Beattie and Fillion (1999)).

No paper, however, has carefully considered the timing of the correlation between intervention and the daily trading rule returns found by LeBaron (1999).[2] This study uses high-frequency trading rule returns and five intervention series from four central banks to investigate whether intervention generates trading rule profits. The data indicate that trading rule returns precede U.S., German and Swiss intervention, casting doubt on the hypothesis that intervention generates technical trading rule profits for these cases. On the other hand, trading rule returns in the AUD/USD do appear to lag Australian intervention. The direction and timing of intervention and trading rule signals makes it implausible that intervention generates trading rule returns even for the AUD/USD, however. Rather, intervention is correlated with trading rule returns because monetary authorities intervene in response to stem short-term trends from which trading rules have recently profited.[3]

---

[1] Davutyan and Pippenger (1989) explored similar issues with Canadian data from the 1950s.
[2] The basic result in this paper—that trading rule returns precede intervention—was mentioned briefly in Neely (1998) and Neely and Weller (2000) but not fully documented in either paper.
[3] This does not, of course, mean that monetary authorities seek to minimize technical trading profits. Instead, authorities might simply dislike the trends themselves.

2. THE DATA

2.1. Intervention Data

This analysis uses five intervention series from four monetary authorities—Australia, Germany, Switzerland and the United States. The Australian intervention data pertain to the Australian dollar/U.S. dollar (AUD/USD) market from 3/4/85 to 6/30/99. The German interventions were conducted in the deutschemark/U.S. dollar (DEM/USD) market from 7/1/83 to 12/31/98. The Swiss intervention was in the Swiss franc/U.S. dollar (CHF/USD) market; these data start on 1/1/86 and end on 12/29/95.[4] Finally, the U.S. intervention data involves in-market transactions in the DEM/USD and Japanese yen/U.S. dollar (JPY/USD) markets from 7/1/83 to 12/31/98.[5] In each case, the starting and ending dates were chosen to maximize the sample size for which intervention data and intraday exchange rates were available.

Table 1 displays the summary statistics in millions of U.S. dollars for the five intervention series. As these intervention series have been described in previous papers, I will note only three points. Panel A of Table 1 shows that almost all intervention series are positively serially correlated. That is, purchases of dollars tend to be followed by purchases of dollars. Panel B shows that the unconditional probability of intervention varies from 43 percent for the Australian series to less than four percent for Swiss intervention. Interventions also tend to cluster together in time. The conditional probability of intervention on day t, given intervention at t-1, varies from 27 percent for Swiss intervention to 75 percent for Australian intervention.

One fact that stands out is that all the purchases are small compared with the $1.5 trillion daily turnover in all currencies in the global foreign exchange market (Bank for International

---

[4] Many results were also computed for Swiss intervention in the DEM/USD and JPY/USD markets. As there were only four and eight observations for these series, the results have been omitted for the sake of brevity.

[5] This study follows LeBaron (1999) in using in-market interventions, which are explicitly designed to change the exchange rate.

Settlements (1999)). The maximum transaction among the five series is a $950 million sale of dollars by the Bundesbank. Skeptics of the effectiveness of foreign exchange intervention have long cited the small size of intervention, relative to the flow of foreign exchange (Edison (1993)). To the extent that this argument is correct, it argues against the hypothesis that intervention could generate trading rule returns.[6]

2.2. Daily exchange rates and interest rates

To correspond with the U.S., German and Swiss intervention series, this paper uses the noon New York (1700 Greenwich Mean Time (GMT)) buying rates for the USD against the DEM, JPY, and CHF from the H.10 Federal Reserve Statistical Release.[7] The daily exchange rate corresponding to the Australian intervention data was the AUD/USD exchange rate collected by the Reserve Bank of Australia at 4:00 p.m. Eastern Australian Time, 0600 GMT.

Daily interest rate data are from the Bank for International Settlements (BIS), collected at 0900 GMT. Australian interest rate data were unavailable over an extended sample so returns for this exchange rate were calculated exclusive of interest differentials. These exchange rate and interest rate series have been described in Neely, Weller and Dittmar (1997) and Neely and Weller (2000); summary statistics are omitted for brevity.

2.3. Intraday exchange rates

The use of daily exchange rates almost inevitably leaves some ambiguity about the timing of

---

[6] Bhattacharya and Weller (1997) counter this argument with a model in which small amounts of intervention can reveal central bank information to private parties, influencing the exchange rate.

[7] Intraday exchange rate collection times will be presented in Greenwich Mean Time (GMT)—also called Universal Time (UT). Table 2 translates GMT into the local time of the location of the intervening monetary authorities. The H.10 data are used for the DEM, JPY and CHF exchange rates, rather than the Data Resources Incorporated (DRI) data used by LeBaron (1999), because the time of collection of the DRI data changes in mid-sample. The DRI data were collected at the New York open (9:00 am New York time) prior to October 8, 1986, and at 11:00 am New York time (the London close) after October 8, 1986. Because most U.S. intervention occurs during the New York

returns and intervention. To address the timing question, four sets of intraday exchange rates have been assembled from daily exchange rates series observed at different times during the day. Data availability necessitated slight differences among the four sets of intraday data. In choosing daily series for inclusion in the intraday data set, a tradeoff was made between maximizing the number of observations per day and retaining the possible greatest time period for the intraday data. This strategy permitted six observations per day for the DEM/USD and CHF/USD, at 0600, 1000, 1400, 1600, 1700 and 2200 GMT. The JPY/USD had one more observation per day, at 0800 GMT. The Australian data were limited to three observations per day, at 2300, 0600, and 1600 GMT.[8] For each intervention series, a maximum sample in which the intervention series, the daily exchange rate and the intraday exchange rates all exist was selected. Thus, the samples varied for each intervention series. Time spans ranged from 10 years for the Swiss intervention in CHF/USD to 15 years, 6 months for the U.S. and German cases.

The data were filtered mechanically to remove obvious outliers—characterized by consecutive six-or-more standard deviation changes in opposite directions—and then rechecked visually. The largest number of outliers was four, for the JPY/USD series. The Data Appendix describes the sources of the intraday data more fully.

Table 3 shows the summary statistics on the log changes in percentage terms. Note that in the computation of the summary statistics, if the observation at t+1 was missing, the return at t was calculated as the return from t to t+2. The series with the highest percentage of missing observations was the AUD/USD data collected at 2300, which had six percent fewer

---

morning, the break in the timing of collection of DRI data creates special problems in determining the temporal ordering of returns and intervention.

[8] Describing the time of collection of the intraday exchange rate data in GMT is an approximation. The data were collected during specified local times, which were then translated into GMT without allowance for daylight savings time changes. Thus, actual times of collection in GMT could vary by an hour from those described. For purposes of this paper, the approximation is not important.

observations than the AUD/USD series collected at 1600.

Despite the irregular nature of the intraday data, the return statistics were grossly similar for each series within an exchange rate set. Most of the mean changes are less than one basis point. There does seem to be some tendency for "overnight" returns—those from 1600 or 1700 GMT to 2200 or 2300 GMT, when European markets are closed—to be slightly larger than other mean returns. The Newey-West–corrected t statistics, with a five-period window, suggest that although these overnight returns are generally very small—in the 1 to 2 basis point range—they are still statistically different from zero. These small overnight returns might simply be compensation for interest differentials rather than anomalies, however. The fact that the DEM/USD, JPY/USD and CHF/USD overnight changes are negative while the AUD/USD changes are positive supports this explanation; the dollar would be expected to depreciate against the relatively low interest DEM, JPY and CHF but appreciate against the high interest AUD. The largest daily seasonality found is in the JPY/USD series; returns from 0800 to 1000 are about 2 basis points while those from 1000 to 1400 are almost –4 basis points. All the results would be robust to the exclusion of the JPY/USD series collected at 1000. The small mean returns imply that the irregular nature of the data does not introduce any seasonality that would be significant for this paper's results.

3. DAILY RETURNS AND INTERVENTION

3.1. Daily Return Results

Before exploring the temporal pattern of trading rule returns with intraday data, let us first review the results with daily returns and intervention for this sample. For continuity with the previous literature, this paper will follow LeBaron's (1999) lead and examine signals from an

MA 150 technical trading rule.[9] The rule prescribes:

$$\text{Buy USD if } S_t \geq \frac{1}{150}\sum_{i=0}^{149} S_{t-i}, \text{ and sell USD if } S_t < \frac{1}{150}\sum_{i=0}^{149} S_{t-i}, \tag{1}$$

where S_t is the spot foreign exchange price of USD at time t.[10]

Excess returns to the rule are calculated under the assumption that a trader holds an amount of money in a margin account that collects the U.S. interest rate. The trader then borrows against that margin to either invest in the foreign currency (short the USD) or to invest in USD assets (short the foreign currency). The continuously compounded (log) excess return to switching back and forth between fully margined long and short positions in the foreign currency is approximated by $z_t r_t$. The variable z_t takes the values of +1 for a long position in USD and -1 for a short position, and r_t is defined as[11]

$$r_t = \ln S_{t+1} - \ln S_t - \ln(1 + i_t^*) + \ln(1 + i_t). \tag{2}$$

The variables i_t^* and i_t denote the daily interest rates on foreign and U.S. investments, respectively. The total excess return, r, for a trading rule during the period from time zero to time T is the sum of the signed daily returns:

$$r = \sum_{t=0}^{T-1} z_t r_t . \tag{3}$$

Panel A of Table 4 shows the mean annual return, standard deviation, t-statistic, Sharpe ratio and trades-per-year from using an MA 150 trading rule on each of the five samples. The rule makes positive returns in all five samples, ranging from 8.72 percent per annum for the

[9] Sapp (1999) has shown that intervention/return results are not overly sensitive to the length of the moving average employed in the technical trading rule.

[10] The signals generated by the moving average rule could depend on whether the exchange rate is defined as dollars per unit of foreign currency or units of foreign currency per dollar. In practice, however, the correlation in the signals generated by the two methods exceeds 99 percent, and the returns are nearly identical. Neely (1998) provides more details on the derivation of the equations for excess returns.

[11] This definition of r_t introduces a very small approximation error in the case of a short position. Note that these calculations include no adjustment for transactions costs. Given that transactions costs for a change of position

JPY/USD from July 1983 to December 1998 to 2.44 percent for the AUD/USD from March 1985 through June 1999. The row labeled p-value shows the chance that such returns would be produced by chance under the null hypothesis of a zero mean return. The only case in which the p-value is greater than 0.05 is that of AUD/USD, for which it is 0.14.

3.2. Removing Periods of Official Intervention

Panel B of Table 4 shows the results from LeBaron's (1999) procedure that removes returns from t-1 to t when there is intervention at t.[12] LeBaron's (1999) sample comprised in-market U.S. intervention in the DEM/USD and JPY/USD markets from 1979 through 1992. Panel B confirms LeBaron's results for other series and different samples to a remarkable degree, with only minor discrepancies. For example, even after removing U.S. intervention in the JPY/USD market from July 1983 through 1998, the annual return is still a healthy and statistically significant 4.5 percent (from 8.7 percent).

The row labeled Markov p-value shows the chance that randomly removing returns—assuming that intervention follows a Markov process—would lower the return as much as removing actual intervention observations, assuming that intervention follows a Markov process. The only case in which the Markov p-value indicates an insignificant relation between returns and intervention is that of the Swiss intervention in the CHF/USD market: it has a 4.4 percent annual return after removing intervention and a Markov p-value of 0.29. The sign of the relation is consistent with other results, however, and the failure to obtain a statistically significant fall in return might simply reflect the poor power of the test statistic in the presence of relatively sparse

---

probably do not much exceed 5 basis points for a large institutional trader and that the rules trade from five to eight times a year, the annual returns net of transactions costs would be 25-40 basis points lower, still well above zero.

[12] Note that the timing of the daily data (1700 GMT for the DEM/USD, JPY/USD and CHF/USD, 0600 for the AUD/USD) includes all Australian, German and Swiss business hours in the return from observation t-1 to t, but only half of the U.S. business day.

Swiss intervention and a shorter sample.

Some of the strongest results are in the AUD/USD market, which has not been previously studied in this context. Removing Australian intervention periods from March 1985 through June 1999 reduces the annual return from 2.44 percent to –2.27 percent. Other strong results are generated by removing Bundesbank intervention in the DEM/USD market from July 1983 through December 1998. This procedure, which reduces the annual return from 6.03 percent to only 1.28 percent, confirms the results of Saacke (1999) and Sapp (1999) using Bundesbank intervention data over other samples.

Figure 1 illustrates predicted daily trading rule returns around periods of intervention. Predicted returns were constructed by regressing daily trading rule returns on leads and lags of an indicator variable for non-zero intervention:

$$z_{t-1}r_{t-1} = a_0 + \sum_{j=-2}^{2} b_j I_{t+j} + \varepsilon_{t-1} \quad (4)$$

where I_{t+j} is an indicator variable taking the value one if there is any intervention on day t+j. The resulting regression coefficients ($\{a_0+b_j\}_{j=-2}^{2}$) are the predicted returns in the 2 days prior to, on the day of and in the 2-days after intervention. The horizontal axis of Figure 1 is labeled in hours from the beginning of the intervention day in GMT; the dating convention has made the returns backward looking in the figure. For example, because the USD, DEM and JPY daily data were collected at 1700 GMT, the predicted return from t-1 to t coincides with the label 1700 for those cases. Similarly, the predicted return from t to t+1 coincides with the label 41 and the return from t+1 to t+2 is labeled 65.[13] The vertical lines in each panel denote the business hours of the day for each of the four intervening countries. U.S. business hours are from 1300 to 2100 hours

[13] 24 hours after 1700 would be 41 in the notation of the figure.

GMT; German and Swiss business hours are 0600-1400 GMT; Australian business hours occur during –0200 to 0600 GMT.

On the whole, Table 4 and Figure 1 confirm LeBaron's (1999) finding that high technical trading rule returns tend to be correlated with periods of intervention. The results—using a broader sample of intervention series and different time periods—are similar to those found by LeBaron (1999) in U.S. data, Szakmary and Mathur (1997) in multinational monthly data or by Saacke (1999) and Sapp (1999) in U.S. and German data.[14]

Figure 1 clearly illustrates the correlation between days of intervention and technical trading rule returns. The coarseness of the daily data makes it difficult to draw firm conclusions regarding temporal patterns in the data, however. For example, because the U.S. returns both from t-1 to t and from t to t+1 could be influenced by intervention at t, these daily data cannot tell us the temporal ordering of the high returns and the intervention.

4. INTRADAY RESULTS

4.1. Definition of returns with intraday results

Intraday returns are calculated as the log change from one intraday price to the next, but exclusive of overnight interest differentials. That is, the ith return on day t is calculated as:

$$r_{i,t} = \ln S_{i+1,t} - \ln S_{i,t} \qquad (5)$$

where $S_{i,t}$ is the ith observation on day t of the foreign exchange price of USD. Intraday returns whose initial observation occurred at or after the time of daily exchange rate collection day t but before the collection time on day t+1 are signed with the day t signal from the MA 150 rule.[15]

[14] Szakmary and Mathur (1997) found that—in monthly data—the results for the CAD/USD were not nearly as strong as for other dollar exchange rates, the DEM/USD, JPY/USD, GBP/USD and CHF/USD.

[15] Recall that the daily DEM/USD, JPY/USD and CHF/USD exchange rates were collected at 1700 GMT while the daily AUD/USD exchange rate was collected at 0600 GMT. One could permit trade at hours other than noon,

Returns to a trading rule over a sample are the sum of signed intraday returns. It should be emphasized that these are intraday returns—several hours long—not simply daily returns recorded at different times of the day.

4.2. Tabular results with intraday data

Table 5 displays the annualized trading rule statistics from signed daily returns, constructed from intraday exchange rates.[16] Comparing Table 5 with Table 4 shows that including or excluding interest differentials makes little difference to results from the data used here. All of the annualized intraday returns excluding interest rate differentials are within 75 basis points of the interest-adjusted daily results in Table 4. The p-values for the null of zero return are only slightly higher than those in Table 4. The largest such statistics are 0.07 and 0.17 for the Swiss and Australian cases, respectively. The similarity between Tables 4 and 5 is consistent with LeBaron's (1999) finding that the correlation between trading rule returns and intervention is robust to the inclusion or exclusion of interest income. It is also consistent with other research that suggests that interest rate differentials are approximately orthogonal to exchange rate returns (Engel (1996)).

As in Table 4, removing daily returns from t-1 to t when there is intervention at t reduces the mean annual return in every case, though again, the size of the reduction varies. Removing Swiss intervention from the CHF/USD return series leaves a still substantial 5.21 percent annual return, whereas removing days of Australian intervention from the AUD/USD series reduces the annualized return to -2.27 percent. The only Markov p-value greater than 0.05 was 0.32, for the Swiss case. In other words—except for the Swiss case—we can reject the null hypothesis that

---

however, given the low frequency of trading for the MA 150 rule, this would not make much difference in the performance of the rule.

[16] Calculations with daily exchange rates—exclusive of interest rates—produce very similar results, of course.

randomly removing returns would lower the mean as much as removing actual intervention.

4.3. The Temporal pattern of returns and intervention

The coarseness of the daily data—collected at noon on day t—left the sequence of returns and intervention unclear. Does intervention precede high trading rule returns, suggesting that the returns are caused by intervention? Or, do high returns precede intervention, indicating that monetary authorities react to predictable trends by "leaning against the wind?" Or, are the returns truly coincident with intervention? The use of intraday exchange rate data provides greater power to distinguish among these three cases.

A procedure similar to that used in Figure 1 is used to characterize the temporal pattern of trading rule returns and intervention. Intraday trading rule returns—where the periods are in hours rather than in business days—are regressed on leads and lags of intervention signals. That is, returns around intervention are predicted by fitted values from the following regression:

$$z_{i,t} r_{i,t} = a_{i,0} + \sum_{j=-2}^{2} b_{i,j} I_{t+j} + \varepsilon_{i,t} \tag{6}$$

where $z_{i,t}$ is the {-1,1} signal from the MA 150 rule associated with the i^{th} period on day t, $r_{i,t}$ is the intraday return from period i to i+1 on day t and I_{t-j} is the j^{th} lag of the indicator variable for non-zero intervention at t.

The top panel (Panel A) of Figure 2 displays the resulting coefficients $((\{a_{i,0}+b_{i,j}\}_{j=-2}{}^{2})$ as the backward-looking predicted intraday returns in the 5 business days around intervention.[17] The estimated $a_{i,0}$ coefficients were very small, consistent with the summary statistics in Table 3. To facilitate the discernment of patterns in the somewhat noisy predicted return data, the lower panel (Panel B) of Figure 2 shows smoothed predicted returns, a backward-looking 24-hour moving average of the predicted returns. The horizontal axes of the figures are labeled in hours from the beginning of the intervention day in GMT. For example, in panel B, an observation labeled –5 would denote the moving average of the returns from 1900 GMT two days prior to intervention to 1900 GMT on the day prior to intervention. The vertical lines in each panel again denote the business hours of the day for the location of each of the intervening monetary authorities.

Business hours are significant because one might reasonably assume that most intervention transactions take place during those hours. Although the U.S. authorities do not publicly release the times of intervention, Goodhart and Hesse (1993) and Humpage (1998) report that it generally occurs before the close of the London markets, at 1600 GMT. There is more information about the timing of Swiss intervention, which is publicly announced. Generally, the Swiss National Bank intervened for the first time at 1400 GMT during joint intervention with the Federal Reserve.[18] As these joint interventions often also involve the Bundesbank, one might surmise that most Bundesbank intervention in the DEM/USD markets occurs contemporaneously with SNB intervention—during the European afternoon or U.S. morning.[19] The timing of Reserve Bank of Australia operations is less certain; the RBA specifically states that intervention may occur during non-business hours (Rankin (1998)).

Figure 2 is consistent with Figure 1 and Tables 4 and 5 in that the backward-looking trading rule returns are usually high from –1700 to 1700 GMT on the day of interventions for the U.S., Swiss and German cases. Figure 2 also reveals patterns that were not apparent from the tables, however. Most importantly, it is clear that the highest U.S., Swiss, and German excess returns

---

[17] Although daily seasonality was a real possibility given the heterogeneity of the intraday data series, examination of the constants showed no evidence that this affected the conclusions drawn from Figure 2.

[18] The author thanks Andreas Fischer of the Swiss National Bank for private communications regarding the timing of Swiss intervention.

[19] The correlations between signed indicators of U.S., Swiss and German intervention range from 0.55 to 0.62 during the 1986-1995 sample.

precede the business hours during which intervention would be carried out. Most of the high returns are finished by 0800 GMT for the U.S. and German cases and by 1000 GMT for the Swiss case. This timing indicates that, for the German, Swiss and U.S. cases, intervention is probably reacting to predictable short-run changes in exchange rates. In other words, the apparent coincidence of intervention and trading rule returns might result from leaning-against-the-wind behavior.[20]

4.4 Morning-to-morning and business day results

We can quantify how much of the abnormal returns in Figure 2 could have preceded intervention by computing the daily returns from intraday returns from early morning to early morning—prior to the business day, instead of noon-to-noon as in Table 5. Panel A of Table 6 shows that the unconditional results for early-morning to early-morning returns for each of the five cases are very similar—not surprisingly—to the noon-to-noon cases presented in Table 5. Panel B shows that removing observations in the 24 hours prior to the beginning of the intervention day reduces the mean returns substantially. But, these high returns precede intervention and therefore could not plausibly have been caused by intervention. In contrast, Panel C removes returns in the 24 hours after the beginning of the intervention day. Intervention might have preceded—and therefore plausibly caused—these returns. But, removing these returns that follow intervention still leaves significant technical trading rule mean returns. The U.S. and Swiss cases still have high mean returns (4.23 and 6.04 percent) that are statistically significant at the 10 percent level. These results are consistent with the hypothesis that intervention responds to strong short-term trends in the market but does not generate technical

[20] As a check on the robustness of the methodology, the same figure was created for isolated interventions—those for which there was no other intervention within two days of another intervention. With 70-95 percent fewer

trading rule returns.

The German intraday results from Panel C of Table 6 show that removing returns during the 24 hours after the start of the day of intervention does reduce the return on the DEM/USD trading rule to 2.18 percent. However, Figure 2 suggests that part of this reduction is caused by high returns after the business day of intervention. One can argue that such post-business returns should be excluded from the calculations because they are less likely to have been caused by intervention. Neely (2000) provides some evidence from a survey of central bankers themselves to support this proposition: 61 percent of respondents believe that the full effect of intervention is felt in a few hours or less. Panels D and E show the results of excluding returns on the business day prior to and the business day of intervention.[21] Excluding returns on the business day of intervention (Panel E) generally leaves the return to the trading rule at significant (or nearly significant) levels for the U.S., Swiss and German cases. For example, the annualized return to the trading rule, after excluding the business day of U.S. intervention, is a hefty 6.99 percent.

In contrast to the U.S., Swiss and German cases, both Figure 2 and Table 6 show that returns are high during and after Australian interventions. For the Australian case, it appears that the timing of returns and intervention alone cannot rule out the hypothesis that intervention might help generate technical trading returns. Inferring causality from such timing is highly speculative, of course. The next section examines evidence on whether the timing and direction of trading and intervention supports such speculation.

---

observations, results for the U.S. and Swiss cases were consistent with Figure 2; those for Germany showed no clear pattern and those for Australia were inconsistent with results shown in Figure 2.

[21] The notes to Table 6 provide the business hours excluded in each case. Business hours were about 12 hours long.

4.5 How might intervention contribute to technical trading profits?[22]

Although the mechanism is not often fully developed in the literature, one can reason out how intervention might generate profits to trend-following trading rules. If one rules out systematically perverse effects of intervention—e.g., USD purchases leading to depreciation of the USD—two stories seem possible. First, intervention to buy dollars might generate a sustained appreciation in the value of the dollar. This would require intervention to precede the sustained appreciation and for intervention to trade in the same direction as the trading rule. That is, when the central bank is buying dollars, the trading rule should also be buying dollars.

The second story is that intervention might temporarily delay a change in the exchange rate, permitting trading rules time to switch positions and profit by trading against the central bank. That is, a central bank might sell dollars as the dollar is appreciating, temporarily depressing the price and allowing traders to buy dollars cheaply and profit on the resumption of the trend. Of course, this assumes that the trading rule switches positions during or shortly after the intervention. If the trading rule does not switch positions during intervention, it can't take advantage of a delayed movement.

The first story requires traders to trade with central banks. The second story requires traders to switch positions to trade against central banks. Neither story fits the facts. Table 7 shows that the MA 150 rule is usually (typically more than 80 percent of the time) trading against the position taken by central banks in periods around intervention. It appears that intervention is not likely to cause technical trading rule returns in a structural sense for any of the cases.

Table 7 is consistent with the alternate explanation that central bank intervention is a response to strong trends in exchange rates. Because the MA 150 rule is a trend-following rule,

---

[22] This discussion will ignore the important question of why such profits are not arbitraged away and concentrate instead on characterizing possible combinations of intervention, technical positions and exchange rate returns that

the fact that central banks generally intervene against the position taken by the rule indicates that they intervene contrary to recent exchange rate changes.

Finally, one might ask if it is possible that intervention is predictable, rationally anticipated, and therefore might follow the trends (and profits) it creates. Because intervention leans against the wind, such an expectations-based story would require that expectations of intervention create systematically perverse effects. That is, expectations of official dollar purchases would have to generate a trend depreciation of the dollar, for example. This story seems implausible.

4.6 Under what conditions do these monetary authorities intervene?

The finding that intervention is correlated with returns to trading rules but apparently does not cause those returns raises the issue of what conditions prompt monetary authorities to intervene. The fact that the technical trading rules trade against intervention—that is, the rules are buying dollars when the central banks are selling dollars and vice versa—implies that central banks intervene to lean against the wind, to counter recent short-term trends in exchange rates. Such a finding would be consistent with empirical research on intervention (Almekinders and Eijffinger (1996)), results of a survey on intervention practices (Neely (2000)) and the public pronouncements of monetary authorities (Board of Governors (1994, p. 64) or Rankin (1998)).

To test the proposition that intervention is a reaction to exchange rate changes, one would like to use the most recent exchange rate changes that are unlikely to be contemporaneous with intervention. For each of the five intervention series, the nearest 24 hours of intraday returns just prior to the business day of intervention are aggregated into the first lag of returns; the 24 hours of returns prior to that are aggregated into the second lag of returns and so on. For the U.S. intervention in DEM and JPY, the last returns used to predict day t intervention end at 1000

---

might generate technical profits.

GMT; for German and Swiss intervention, the last such returns end at 0600; and for Australian intervention the last returns used end at 1600 GMT on day t-1. Note that it is necessary to use Australian returns data from day t-1 as the Australian business day on day t begins at 2200 GMT of day t-1.

Intervention might also be used to signal to the market that exchange rates are misaligned with their fundamental determinants. Neely (2000) finds that 66.7 percent of responding authorities stated that a desire to return exchange rates to fundamental values *sometimes* or *always* motivated intervention. A simple measure of a monthly purchasing-power-parity exchange rate is constructed with the following regression:

$$\ln(S_t) - \ln(P_t^*) + \ln(P_t) = \mu + \beta\, t + \varepsilon_t \tag{7}$$

where S_t is the foreign exchange price of dollars, P_t^* and P_t are the foreign and U.S. price levels, and t denotes a time trend. The fitted values for $\ln(S_t)$ are linearly interpolated to business day frequency. The deviations of the actual exchange rate from its fitted values measure the misalignment from what the monetary authorities might regard as long-run fundamentals.

To characterize the reaction of intervention to past returns and the measure of misalignment, an intervention reaction function is estimated in a friction-model framework.[23] A friction model permits the dependent variable—intervention—to be insensitive to changes in the independent variables over some range of values. This is appropriate for a variable like intervention that takes the value zero for a large proportion of observations. The likelihood function is given by:

$$L(\alpha_1, \alpha_2, \beta, \sigma \mid I_t, x_t) = \begin{matrix} \prod_{t \in T_1} \frac{1}{\sigma} \phi\left(\frac{I_t + \alpha_1 - \beta' x_t}{\sigma}\right) \times \prod_{t \in T_2} \left[\Phi\left(\frac{\alpha_2 - \beta' x_t}{\sigma}\right) - \Phi\left(\frac{\alpha_1 - \beta' x_t}{\sigma}\right)\right] \\ \times \prod_{t \in T_3} \frac{1}{\sigma} \phi\left(\frac{I_t + \alpha_2 - \beta' x_t}{\sigma}\right) \end{matrix} \tag{8}$$

[23] Almekinders and Eijffinger (1996) and Kim and Sheen (1999) have studied intervention with friction models.

where I_t is intervention at time t, α_1 (< 0) is the lower bound on insensitivity for changes in the linear combination of explanatory variables ($\beta' x_t$) to affect I_t, α_2 (> 0) is the corresponding upper bound, $\{\phi, \Phi\}$ denote the normal density and cumulative normal density, respectively, and T_1, T_2 and T_3 denote the sets of observations for which I_t is negative, zero and positive, respectively.

Up to five lags of intervention, up to five lags of 24-hour cumulated returns and the deviation of the exchange rate were permitted for each intervention series and the models were estimated by maximum likelihood, subject to the constraint that the estimated model be stationary.[24] The best model was selected by the Schwarz criterion (SC).

Table 8 displays the coefficients from the best models as well as the results of two likelihood ratio tests. Consistent with the autocorrelation found in the summary statistics, the coefficients on lagged intervention are generally positive. Coefficients on lagged returns are negative—indicating leaning-against-the-wind behavior. The coefficient on the exchange rate deviation is also negative in each case, meaning that monetary authorities tend to buy dollars when the value of the dollar is below its purchasing-power-parity fundamental measure and sell dollars when the dollar is above that measure. It is difficult to assess the economic plausibility of the ranges of inaction $\{\alpha_1, \alpha_2\}$, because they apply to a linear combination of independent variables. It is reassuring, however, that the range of inaction is smaller for Australia, which intervened more frequently than the other authorities. The first hypothesis tested by likelihood ratio is that the coefficient(s) on the lag(s) of the exchange rate return are jointly zero. This restriction is overwhelmingly rejected in each case. The second hypothesis is that the coefficient on the exchange rate deviation is zero. The only case for which we fail to reject this restriction is that of the AUD/USD, for which the coefficient is of the correct sign but insignificant. Intervention tends to lean against the wind and to be in the correct direction to reduce misalignment.

A common problem in estimating time series relations, such as reaction functions, is structural instability. To test for structural stability in a model at a known break point, T_0, one can estimate the model before and after T_0 and use the resulting parameter estimates, $\hat{\theta}_1$ and $\hat{\theta}_2$, and their covariance matrices, V_1 and V_2, to compute a Wald test statistic (Hamilton (1994)):

$$\lambda = \left(\hat{\theta}_1 - \hat{\theta}_2\right)' \left[V_1 + V_2\right]^{-1} \left(\hat{\theta}_1 - \hat{\theta}_2\right). \tag{9}$$

Under the null hypothesis of no structural break at T_0, the test statistic is distributed as a chi-square random variable with degrees of freedom equal to the number of parameters being tested. The null of no structural break at T_0 is rejected for sufficiently high values of λ.

Wald tests for structural breaks in the middle of each sample failed to reject structural stability in every case, except that of the AUD/USD.[25] Even in this case, the qualitative inference on the coefficients over each subsample was the same as that drawn from the whole sample: Intervention is negatively related to recent trends in exchange rates and to deviations from the purchasing-power-parity fundamental means. Thus, the determinants of central bank intervention appear structurally stable. Full results are omitted for brevity.

5. CONCLUSION

During the last 15 years, researchers have accumulated evidence that technical trading rules can produce excess returns in foreign exchange markets. These returns cannot be readily explained by reasonable transactions costs, conventional measures of risk or data mining. For a long time, some have speculated that these trading rule returns result from official intervention.

---

[24] There was great difficulty fitting the models for U.S. intervention with more than three intervention lags, so those results were not considered.

Many have interpreted recent research as confirming this suspicion. LeBaron (1999), Saacke (1999) and Sapp (1999) found strong correlations between periods of U.S. and German intervention and high trading rule returns. Szakmary and Mathur (1997) extended this research to multinational monthly data.

The primary contribution of this paper is to show that the high frequency evidence disproves the hypothesis that intervention generates trading rule profits. Instead, intervention reacts to the same strong short-run trends from which the trading rules have recently profited.

In addition to showing that intervention does not generate trading rule profits, this paper characterizes the temporal patterns of high frequency trading rule returns and intervention for Australian, German, Swiss and U.S. intervention. Positive correlations found in German and U.S. data are also present—with minor variations—in longer samples and in Australian and Swiss data. For the U.S., German and Swiss cases, the highest returns probably precede intervention by less than 24 hours. For Australia, the highest returns appear to be coincident with or follow the likely hours of intervention. However, examination of the direction of trading signals and intervention make it implausible that intervention is actually generating those returns.

---

[25] The finding of instability in the RBA's reaction function might not surprise those who have read Rankin (1998), who describes five distinct periods of intervention behavior by the RBA during this sample.

Data Appendix

	Collection Time (GMT)	Date 1	Date 2	Source	Type of Price
DEM/USD	6	19830701	19981231	Reserve Bank of Australia	triangular arbitrage on mid points
	10	19830701	19981231	Swiss National Bank	triangular arbitrage on bid rates
	14	19830701	19981231	Federal Reserve Bank of New York	mid point of bid and ask
	16	19830701	19981231	Bank of England	triangular arbitrage, unspecified
	17	19830701	19981231	Federal Reserve Bank of New York	mid point of bid and ask
	22	19830701	19981231	Federal Reserve Bank of New York	mid point of bid and ask
JPY/USD	6	19830701	19981230	Reserve Bank of Australia	triangular arbitrage on mid points
	8	19830701	19981230	Bank of Japan	unspecified, representative
	10	19830701	19981230	Swiss National Bank	Triangular arbitrage on bid rates
	14	19830701	19981230	Federal Reserve Bank of New York	Mid point of bid and ask
	16	19830701	19981230	Bank of England	Triangular arbitrage, unspecified
	17	19830701	19981230	Federal Reserve Bank of New York	Mid point of bid and ask
	22	19830701	19981230	Federal Reserve Bank of New York	Mid point of bid and ask
CHF/USD	6	19860103	19951229	Reserve Bank of Australia	Triangular arbitrage on mid points
	10	19860103	19951229	Swiss National Bank	bid rates
	14	19860103	19951229	Federal Reserve Bank of New York	mid point of bid and ask
	16	19860103	19951229	Bank of England	triangular arbitrage, unspecified
	17	19860103	19951229	Federal Reserve Bank of New York	mid point of bid and ask
	22	19860103	19951229	Federal Reserve Bank of New York	mid point of bid and ask
AUD/USD	23 (t-1)	19850303	19990629	Reserve Bank of New Zealand	triangular arbitrage on mid points
	6	19850304	19990630	Reserve Bank of Australia	mid point of bid and ask
	16	19850304	19990630	Bank of England	triangular arbitrage, unspecified

Notes: The table describes the sources and collection times of the intraday exchange rates used in the paper. Column 1 provides the exchange rate while column 2 shows the collection time in GMT. Columns 3 and 4 show the beginning and ending dates of the sample in YYYYMMDD format. The fifth column shows the source of the data while the sixth displays any available details on the type of price or how the exchange rate was calculated.

References

Almekinders, G. and S.C.W. Eijffinger, 1996, A friction model of daily Bundesbank and Federal Reserve intervention, Journal of Banking and Finance 20, 1365-1380.

Bank for International Settlements, 1999, Central bank survey of foreign exchange and derivatives market activity 1998 (Basle, Switzerland).

Beattie, N. and J-F. Fillion, 1999, An Intraday Analysis of the Effectiveness of Foreign Exchange Intervention, Bank of Canada Working Paper 99-4, February.

Bhattacharya, U. and P. Weller, 1997, The advantage to hiding one's hand: speculation and central bank intervention in the foreign exchange market. Journal of Monetary Economics 39, 251-277.

Board of Governors of the Federal Reserve System, 1994, The Federal Reserve System: Purposes and Functions (Washington, DC).

Chang, Y. and S. J. Taylor, 1998, Intraday Effects of Foreign Exchange Intervention by the Bank of Japan, Journal of International Money and Finance 17, 191-210.

Corrado, C. and D. Taylor, 1986, The cost of a central bank leaning against a random walk, Journal of International Money and Finance 5, 303-314.

Davutyan, N. and J. Pippenger, 1989, Excess returns and official intervention: Canada 1952-1960, Economic Inquiry 27, 489-500.

Dooley, M. and J. Shafer, 1983, Analysis of short-run exchange rate behavior: March 1973 to November 1981 in: D. Bigman and T. Taya, eds., Exchange rate and trade instability: causes, consequences, and remedies (Ballinger, Cambridge, MA) .

Edison, H., 1993, The effectiveness of central-bank intervention: a survey of the literature after 1982, Princeton University, Department of Economics, Special Papers in International Economics, No. 18.

Engel, C., 1996, The forward discount anomaly and the risk premium: a survey of recent evidence, Journal of Empirical Finance 3, 123-192.

Fischer, A. M. and M. Zurlinden, 1999, Exchange rate effects of central bank interventions: an analysis of transaction prices, Economic Journal 109, 662-676.

Friedman, M., 1953, The case for flexible exchange rates, essays in positive economics (University of Chicago Press, Chicago).

Goodhart, C. A. E., and T. Hesse., 1993, Central bank forex intervention assessed in continuous time, Journal of International Money and Finance 12, 368-389.

Hamilton, J., 1994, Time Series Analysis, (Princeton University Press, Princeton).

Humpage, O., 1998, U.S. Intervention: assessing the probability of success, Federal Reserve Bank of Cleveland Working Paper 9608.

Jensen, M., 1978, Some anomalous evidence regarding market efficiency, Journal of Financial Economics 6, 95-101.

Kho, B-C., 1996, Time-varying risk premia, volatility, and technical trading rule profits: evidence from foreign currency futures markets, Journal of Financial Economics 41, 249-290.

Kim, S. and J. Sheen, 1999, The determinants of foreign exchange intervention by central banks: evidence from Australia, The University of New South Wales, unpublished manuscript.

Kritzman, M., 1989, Serial dependence in currency returns: investment implications, Journal of Portfolio Management 16, 96-102.

Leahy, M., 1995, The profitability of US intervention in the foreign exchange markets, Journal of International Money and Finance 14, 823-844.

LeBaron, B., 1999, Technical trading rule profitability and foreign exchange intervention, Journal of International Economics 49, 125-143.

Levich, R. and L. Thomas, 1993, The significance of technical trading rule profits in the foreign exchange market: a bootstrap approach, Journal of International Money and Finance 12, 451-474.

Neely, C., 2000, The practice of central bank intervention: looking under the hood, Central Banking 11, 24-37.

Neely, C., 1998, Technical analysis and the profitability of US foreign exchange intervention, Federal Reserve Bank of St. Louis Review, 3-17.

Neely, C, and P. Weller, 2000, Technical analysis and central bank intervention, Federal Reserve Bank of St. Louis Working Paper 97-002C, Forthcoming in the Journal of International Money and Finance.

Neely C., P. Weller and R. Dittmar, 1997, Is technical analysis in the foreign exchange market profitable? A genetic programming approach, Journal of Financial and Quantitative Analysis 32, 405-426.

Peiers, Bettina, 1997, Informed traders, intervention and price leadership: a deeper view of the microstructure of the foreign exchange market, Journal of Finance 52, 1589-1614.

Rankin, B., 1998, The exchange rate and the reserve bank's role in the foreign exchange market, http://www.rba.gov.au/publ/pu_teach_98_2.html.

Ready, M., 1998, Profits from technical trading rules, University of Wisconsin, unpublished manuscript.

Saacke, P., 1999, Technical analysis and the effectiveness of central bank intervention, University of Hamburg, unpublished manuscript.

Sapp, S., 1999, The role of central bank intervention in the profitability of technical analysis in the foreign exchange market, Ivey School of Business, University of Western Ontario, unpublished manuscript.

Silber, W., 1994, Technical trading: when it works and when it doesn’t, Journal of Derivatives 1, 39-44.

Sullivan, R., A. Timmermann and H. White, 1999, Data-snooping, technical trading rule performance, and the bootstrap, Journal of Finance 54, 1647-1691.

Sweeney, R., 1986, Beating the foreign exchange market, Journal of Finance 41, 163-182.

Szakmary, A. and I. Mathur, 1997, Central bank intervention and trading rule profits in foreign exchange markets, Journal of International Money and Finance 16, 513-535.

Table 1: Summary statistics on central bank intervention

Panel A: Unconditional Statistics

Monetary Authority	Exchange Rate	Date1	Date2	Obs	μ	$\lvert\mu\rvert$	σ	min	max	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5
United States	DEM/USD	19830701	19981231	4043	-1.27	8.82	52.89	-797.0	950.0	0.30	0.23	0.19	0.16	0.15
Germany	DEM/USD	19830701	19981231	3777	-6.04	11.12	52.72	-950.8	722.0	0.36	0.30	0.20	0.23	0.17
United States	JPY/USD	19830701	19981230	4042	0.14	7.89	49.48	-833.0	800.0	0.38	0.28	0.28	0.26	0.20
Switzerland	CHF/USD	19860103	19951229	2606	-0.90	2.46	19.02	-545.0	150.0	0.07	0.06	0.14	0.05	0.05
Australia	AUD/USD	19850304	19990630	3630	4.50	19.37	57.99	-933.7	437.3	0.48	0.26	0.19	0.18	0.18

Panel B: Statistics conditional on intervention

Monetary Authority	Exchange Rate	Date1	Date2	Obs	μ	$\lvert\mu\rvert$	σ	$P(I_t \neq 0)$	$P(I_t \neq 0 \mid I_{t-1} = 0)$	$P(I_t \neq 0 \mid I_{t-1} \neq 0)$
United States	DEM/USD	19830701	19981231	228	-22.52	156.43	222.10	0.06	0.03	0.49
Germany	DEM/USD	19830701	19981231	474	-48.12	88.61	141.99	0.13	0.05	0.65
United States	JPY/USD	19830701	19981230	197	2.93	161.90	224.65	0.05	0.03	0.50
Switzerland	CHF/USD	19860103	19951229	101	-23.12	63.51	94.39	0.04	0.03	0.27
Australia	AUD/USD	19850304	19990630	1549	10.54	45.39	88.43	0.43	0.19	0.75

Notes: The table shows summary statistics on intervention by four central banks in four exchange rates. All figures show USD purchases in millions of USD. The top panel shows the unconditional statistics while the bottom panel shows statistics conditional on intervention. μ is the mean of the series, $\lvert\mu\rvert$ is the mean of the absolute value of the series, σ is the standard deviation of the series, min and max are the extrema, while ρ_1, ρ_2, ρ_3, ρ_4 and ρ_5 are the first five autocorrelations. In the bottom panel: $P(I_t \neq 0)$ is the unconditional probability of intervention. $P(I_t \neq 0 \mid I_{t-1} = 0)$ is the probability of a non-zero intervention at t, conditional on no intervention at t-1. $P(I_t \neq 0 \mid I_{t-1} \neq 0)$ is the probability of a non-zero intervention at t, conditional on non-zero intervention at t-1. All statistics are calculated on the basis of business days, not calendar days.

Table 2: Time Zones of Intervention vs. Greenwich Mean Time

Eastern Australia	Frankfurt and Zurich	Greenwich Mean Time	New York
10	1	0	19
11	2	1	20
12	3	2	21
13	4	3	22
14	5	4	23
15	6	5	0
16	7	6	1
17	8	7	2
18	9	8	3
19	10	9	4
20	11	10	5
21	12	11	6
22	13	12	7
23	14	13	8
0	15	14	9
1	16	15	10
2	17	16	11
3	18	17	12
4	19	18	13
5	20	19	14
6	21	20	15
7	22	21	16
8	23	22	17
9	0	23	18

Notes: The table translates Greenwich Mean Time in local standard times for the intervening monetary authorities.

Table 3: Summary statistics on intraday exchange rate changes

	Time1	Time2	Date1	Date2	Obs	μ	$\|\mu\|$	σ	t-stat	min	max	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5
DEM/USD	6	10	19830701	19981231	3929	0.009	0.17	0.24	2.34	-1.58	1.55	0.00	-0.03	0.02	0.01	-0.03
Changes	10	14	19830701	19981231	3914	-0.006	0.22	0.33	-1.05	-2.66	2.63	-0.01	0.02	0.05	-0.01	0.00
	14	16	19830701	19981231	3911	-0.004	0.21	0.28	-0.82	-1.90	2.16	-0.05	0.04	-0.01	0.01	0.02
	16	17	19830701	19981231	3939	0.000	0.15	0.22	-0.10	-1.70	1.60	-0.01	0.04	0.02	0.00	0.00
	17	22	19830701	19981231	3867	-0.013	0.21	0.28	-2.99	-2.05	2.10	-0.05	0.00	0.00	-0.02	0.01
	22	6	19830701	19981231	3904	0.003	0.20	0.29	0.76	-2.49	3.46	-0.03	-0.02	-0.01	0.00	-0.02
JPY/USD	6	8	19830701	19981230	3928	-0.002	0.10	0.17	-0.62	-1.85	1.37	-0.02	0.00	-0.02	-0.01	0.05
Changes	8	10	19830701	19981230	3843	0.023	0.13	0.18	7.93	-1.09	1.65	-0.02	-0.05	0.03	-0.02	0.00
	10	14	19830701	19981230	3913	-0.038	0.19	0.34	-7.13	-4.47	3.50	0.05	0.03	0.05	0.03	0.04
	14	16	19830701	19981230	3906	0.005	0.17	0.28	1.16	-2.51	2.44	0.04	0.06	0.00	0.01	0.02
	16	17	19830701	19981230	3938	0.004	0.12	0.18	1.44	-2.25	1.50	-0.01	0.01	0.03	-0.01	0.00
	17	22	19830701	19981230	3870	-0.007	0.18	0.27	-1.75	-2.84	2.23	-0.03	-0.02	0.01	0.02	0.01
	22	6	19830701	19981230	3903	-0.003	0.25	0.35	-0.46	-2.88	2.85	-0.02	-0.02	-0.03	-0.02	0.03
CHF/USD	6	10	19860103	19951229	2534	-0.011	0.20	0.28	-1.91	-1.67	1.62	0.02	-0.03	0.02	0.02	-0.02
Changes	10	14	19860103	19951229	2525	0.010	0.25	0.38	1.35	-1.76	2.94	-0.01	0.03	0.04	0.01	0.00
	14	16	19860103	19951229	2505	0.003	0.25	0.33	0.41	-2.25	2.42	-0.06	0.07	-0.03	0.01	0.01
	16	17	19860103	19951229	2540	-0.003	0.18	0.25	-0.64	-1.82	1.44	-0.04	0.04	0.01	-0.02	0.02
	17	22	19860103	19951229	2497	-0.019	0.23	0.32	-2.96	-2.22	1.91	-0.02	0.00	0.01	-0.03	-0.01
	22	6	19860103	19951229	2502	-0.002	0.23	0.33	-0.37	-2.53	2.79	0.00	-0.01	0.00	-0.01	-0.01
AUD/USD	-1	6	19850304	19990630	3422	-0.009	0.19	0.32	-1.66	-2.52	3.53	0.05	0.03	-0.03	0.01	0.02
Changes	6	16	19850304	19990630	3630	-0.013	0.27	0.44	-1.80	-3.35	3.25	0.09	0.02	0.03	0.02	0.00
	16	23	19850304	19990630	3636	0.024	0.26	0.40	3.66	-3.67	3.14	-0.01	-0.01	-0.02	0.00	0.06

Notes: The table presents summary statistics on the intraday percentage log changes in exchange rates. The four panels show the statistics for the DEM/USD, JPY/USD, CHF/USD and AUD/USD respectively. The columns labeled *Time1* and *Time2* show the time (in GMT) of the initial and final price in the return calculation. The DEM/USD row labeled *{6,10}* for example, shows summary statistics for log returns from 0600 to 1000 GMT. The first observation for the AUD/USD begins one hour before midnight of day t. Starting and ending dates for the data are shown in the columns labeled *Date1* and *Date2*. *t-stat* denotes the Newey-West corrected t-statistic for the null hypothesis that the mean return is equal to zero. See the notes to Table 1 for descriptions of *Obs,* μ, $|\mu|$, σ, *min, max,* $\rho_1, \rho_2, \rho_3, \rho_4$ and ρ_5.

Table 4: Daily trading rule returns conditional on removing periods of intervention

Monetary	Authority	United States	Germany	United States	Switzerland	Australia
Exchange	Rate	DEM/USD	DEM/USD	JPY/USD	CHF/USD	AUD/USD
Panel A: All observations						
	obs	3892	3892	3891	2512	3629
	mean	6.03	6.03	8.72	5.10	2.44
	std	0.69	0.69	0.68	0.79	0.62
	t-stat	2.17	2.17	3.17	1.28	0.93
	sharpe	0.55	0.55	0.80	0.41	0.25
	ntrades	7.55	7.55	5.23	6.41	8.17
	p-value	0.01	0.00	0.00	0.05	0.14
Panel B: Remove p(t)/p(t-1) when I(t) /= 0						
	obs	3661	3302	3692	2410	2080
	mean	2.61	1.28	4.50	4.44	-2.27
	std	0.67	0.67	0.66	0.78	0.55
	t-stat	0.99	0.51	1.74	1.16	-1.30
	sharpe	0.25	0.13	0.44	0.37	-0.34
	ntrades	7.42	7.29	5.23	6.21	5.52
	p-value	0.13	0.40	0.02	0.11	0.86
	Markov-p	0.00	0.00	0.00	0.29	0.00
	date 1	19830701	19830701	19830701	19860103	19850304
	date 2	19981231	19981231	19981230	19951229	19990630

Notes: The table shows the results of an MA 150 rule on daily foreign exchange rate data with interest rates in the return calculations, except for the AUD/USD. Panel A shows the results for all observations. Panel B excludes return observations from t-1 to t for which there was non-zero intervention at t. *obs* is the number of observations in each sample. *mean* is the mean annualized return to the rule in percentage terms. *std* is the standard deviation of the daily returns in percentage terms. *t-stat* is the t-statistic for the null hypothesis that the mean annual return is zero. *sharpe* is the annualized Sharpe ratio for the rule. *ntrades* is the number of trades per year. *p-value* is the p-value for the test of the null that the mean return is zero. Low p-values reject the null hypothesis. In panel B, *Markov-p* shows the simulated p-value for the test of the null that the change in the mean annual return from Panel A to Panel B would have been as great by randomly removing returns. *Date 1* and *date 2* are the beginning and ends of the samples in yyyymmdd format.

Table 5: Trading rule returns with intraday data, conditional on removing periods of intervention

Monetary	Authority	United States	Germany	United States	Switzerland	Australia
Exchange	Rate	DEM/USD	DEM/USD	JPY/USD	CHF/USD	AUD/USD
Panel A: All observations						
	obs	3892	3892	3891	2512	3629
	mean	5.98	5.98	8.29	5.84	2.44
	std	0.69	0.69	0.68	0.79	0.62
	tstat	2.15	2.15	3.01	1.47	0.93
	sharpe	0.55	0.55	0.76	0.47	0.25
	ntrades	7.55	7.55	5.23	6.41	8.17
	p-value	0.02	0.02	0.00	0.07	0.17
Panel B: Remove p(t)/p(t-1) when I(t) /= 0						
	obs	3661	3302	3692	2410	2080
	mean	2.59	1.47	4.20	5.21	-2.27
	std	0.67	0.67	0.66	0.78	0.55
	tstat	0.99	0.59	1.62	1.37	-1.30
	sharpe	0.25	0.15	0.41	0.43	-0.34
	ntrades	7.42	7.29	5.23	6.21	5.52
	p-value	0.19	0.32	0.05	0.12	0.91
	Markov-p	0.00	0.00	0.00	0.32	0.00
	date 1	19830701	19830701	19830701	19860103	19850304
	date 2	19981231	19981231	19981230	19951229	19990630

Notes: See the notes to Table 4.

Table 6: Morning to morning returns with and without days and business days of intervention.

Monetary Exchange	Authority Rate	United States DEM/USD	Germany DEM/USD	United States JPY/USD	Switzerland CHF/USD	Australia AUD/USD
Panel A: All observations						
	obs	3891	3891	3890	2511	3628
	mean	5.87	5.89	8.28	5.91	2.40
	tstat	1.99	1.97	2.95	1.43	0.90
	p-value	0.02	0.01	0.01	0.05	0.20
Panel B: Remove p(t)/p(t-1) when I(t) /= 0						
	obs	3660	3301	3691	2409	2080
	mean	2.28	0.05	3.69	2.95	-0.65
	tstat	0.82	0.02	1.38	0.74	-0.35
	p-value	0.18	0.49	0.07	0.19	0.61
	Markov-p	0.00	0.00	0.00	0.00	0.05
Panel C: Remove p(t+1)/p(t) when I(t) /= 0						
	obs	3661	3302	3692	2410	2080
	mean	4.23	2.18	6.02	6.04	-2.65
	tstat	1.50	0.79	2.28	1.52	-1.46
	p-value	0.07	0.22	0.00	0.09	0.86
	Markov-p	0.00	0.00	0.00	0.67	0.01
Panel D: Remove business hour returns prior to the day of intervention						
	obs	3775.00	3620.04	3790.00	2463.71	3111.33
	mean	3.32	1.95	5.75	3.56	1.32
	tstat	1.21	0.75	2.16	0.89	0.70
	p-value	0.11	0.28	0.03	0.24	0.29
	Markov-p	0.00	0.00	0.00	0.00	0.35
Panel E: Remove business hour returns on the day of intervention						
	obs	3776.00	3621.04	3791.00	2464.71	3112.00
	mean	3.90	3.31	6.99	5.91	-0.30
	tstat	1.41	1.26	2.66	1.50	-0.16
	p-value	0.10	0.11	0.02	0.05	0.57
	Markov-p	0.00	0.02	0.04	0.52	0.11
	date 1	19830701	19830701	19830701	19860103	19850304
	date 2	19981231	19981231	19981230	19951229	19990630

Notes: The table provides statistics on returns calculated from morning to morning, starting prior to the business day in each intervening country. The hours over which the returns are calculated for the five cases are 1000, 0600, 1000, 0600, and 1600 (of t-1) GMT. In local times, these would be 0500, 0700, 0500, 0700 and 0200, respectively. See the notes to Table 4 for definitions of *obs, mean, tstat, p-value,* and *Markov-p*. Panel A shows the results for all observations. Panel B removes the returns in the 24 hours prior to the beginning of the morning observation when there is intervention. Panel C removes the returns in the 24 hours after the morning observation when there is intervention. Panel D removes the returns during the business day prior to the day of intervention. Panel E removes the returns during the business day of intervention. Business day hours are calculated as 1000-2200, 0600-1700, 1000-2200, 0600-1700, and 1600 (day t-1) to 0600 GMT for each of the five cases, respectively. The number of observations in Panels C and D refers to the number of 24-hour periods and so need not be an integer value.

Table 7: Do the technical traders trade with or against central banks?

Authority Rate	United States DEM/USD	Germany DEM/USD	United States JPY/USD	Switzerland CHF/USD	Australia AUD/USD
-2	0.05	0.06	0.06	0.05	0.19
-1	0.06	0.07	0.07	0.04	0.19
0	0.15	0.12	0.13	0.13	0.28
1	0.06	0.07	0.07	0.04	0.20
2	0.04	0.06	0.06	0.05	0.20

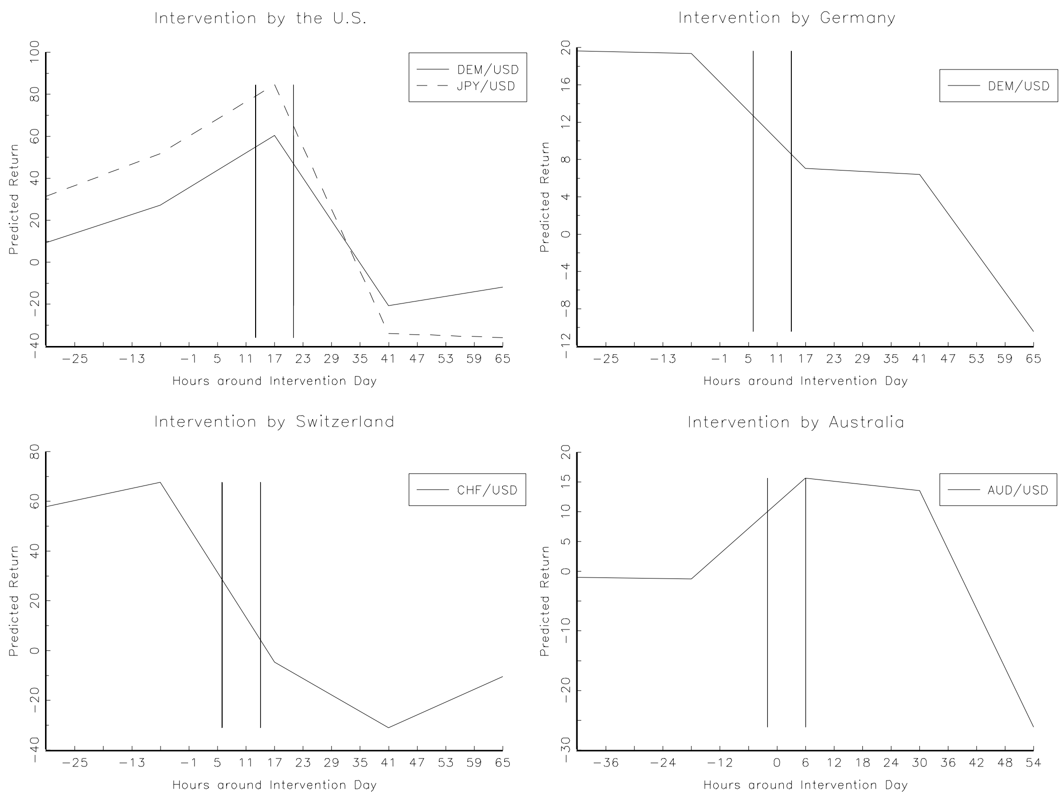
Notes: The table shows the proportion of the time that the MA 150 trader and the monetary authority were on the same side of the market from two days prior to intervention to two days after intervention. For example, the third row, second column shows that MA 150 traders were purchasing (selling) dollars only 5 percent of the time before U.S. authorities purchased (sold) dollars. The timing convention is that intervention at t is contemporaneous with the trading position from t-1 to t.

Table 8: Under what conditions do monetary authorities intervene?

	United States DEM/USD		Germany DEM/USD		United States JPY/USD		Switzerland CHF/USD		Australia AUD/USD	
I1 (s.e.)	0.95	(0.00)	0.60	(0.06)	0.95	(0.00)	0.95	(0.00)	0.74	NA
I2 (s.e.)			0.33	(0.05)					-0.09	NA
I3 (s.e.)									0.13	NA
R1 (s.e.)	-6.95	(1.26)	-4.40	(0.62)	-6.63	(1.28)	-3.40	(0.90)	-0.52	NA
R2 (s.e.)			-2.75	(0.61)			-2.85	(0.89)	-0.27	NA
R3 (s.e.)			-3.31	(0.62)			-3.11	(0.92)		
R4 (s.e.)							-2.58	(0.93)		
XRD (s.e.)	-0.41	(0.06)	-0.51	(0.03)	-0.63	(0.08)	-0.88	(0.12)	-0.16	NA
σ (s.e.)	0.31	(0.02)	0.17	(0.01)	0.29	(0.02)	0.16	(0.01)	0.08	NA
$\alpha 1$ (s.e.)	-0.59	(0.03)	-0.28	(0.01)	-0.59	(0.04)	-0.29	(0.03)	-0.11	NA
$\alpha 2$ (s.e.)	0.65	(0.04)	0.40	(0.02)	0.64	(0.04)	0.49	(0.04)	0.06	NA
LR test, p-value	52.50	(0.00)	433.61	(0.00)	83.00	(0.00)	88.15	(0.00)	153.52	(0.00)
LR test, p-value	33.33	(0.00)	101.03	(0.00)	28.77	(0.00)	47.10	(0.00)	3.45	(0.18)

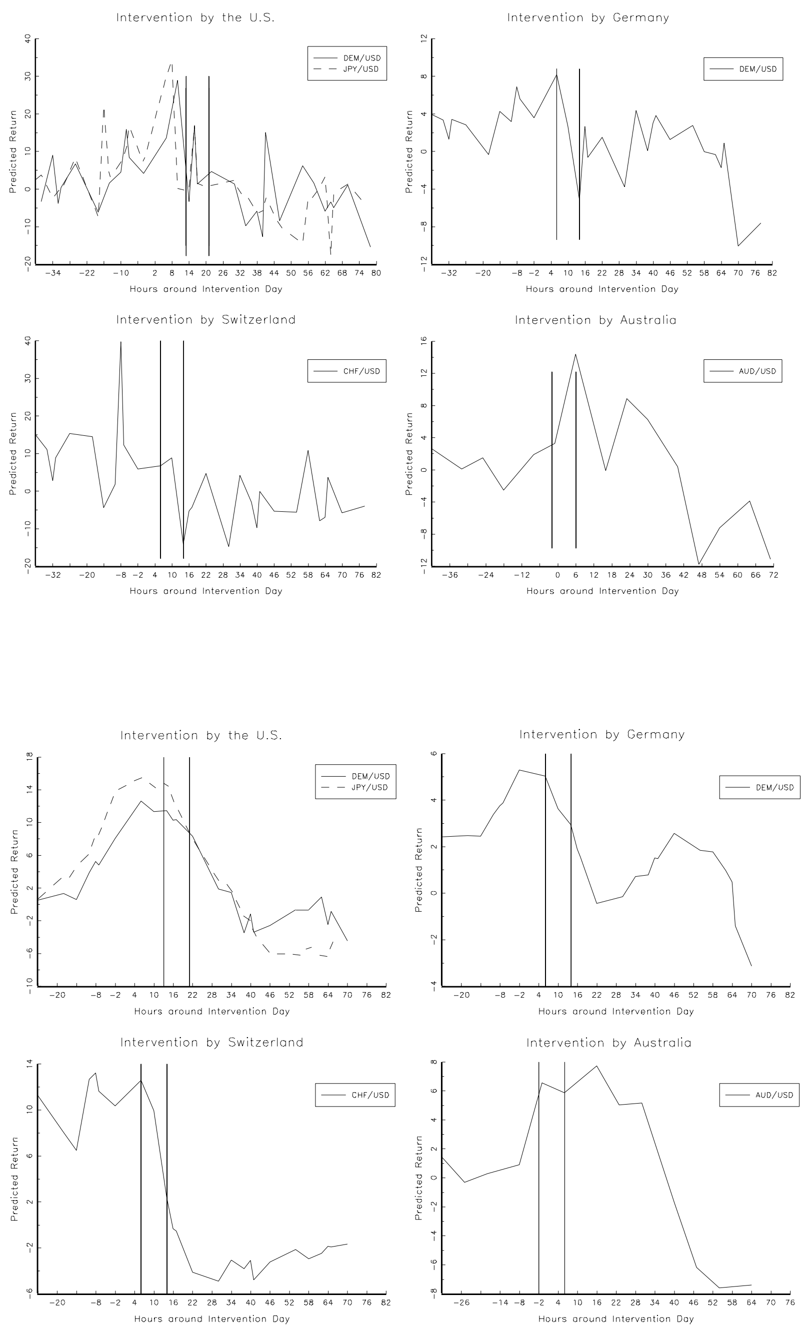
Notes: The table shows the results from a friction model estimating monetary authority reaction functions. Equation (8) in the text shows the likelihood function. The best models were selected from maximal lag lengths of 5 lags of intervention and 5 lags of returns by the Schwarz criterion. The top panel shows the coefficient estimates and standard errors. The coefficients on lags of intervention are labeled I1 to I5, that on the lagged return variable as R1 and the coefficient on the exchange rate deviation as XRD. The bottom panel shows the results of likelihood ratio tests for two hypotheses: 1) that the coefficients on lagged returns are zero—that the authority doesn't lean against the wind; 2) that the coefficient on the deviation from purchasing power parity is zero—that the authority does not intervene to correct misalignments. NA indicates that standard errors were unavailable as the Hessian was near singular.

Figure 1: Daily trading rule returns around periods of intervention



Notes: The figure depicts predicted daily backward-looking returns to an MA 150 rule around periods of intervention—obtained by regressing trading rule returns on leads and lags of intervention. The vertical lines depict the business day of intervention in the intervening country. Australian business hours are –0200 to 0600 GMT; German and Swiss business hours are 0600 to 1400 GMT; U.S. business hours are 1300 to 2100 hours GMT. The horizontal axis shows hours before (negative) and after (positive) midnight on the day of intervention in GMT.

Figure 2: Intraday trading rule returns around periods of intervention



Notes: The figure depicts predicted backward-looking intraday returns to an MA 150 rule around periods of intervention—obtained by regressing intraday trading rule returns on leads and lags of intervention. The top panel depicts annualized intraday returns while the bottom panel depicts the 24-hour backward-looking moving average of those returns. The vertical lines depict the business day of intervention in the intervening country. The horizontal axis shows hours before (negative) and after (positive) midnight on the day of intervention in GMT.