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The temporal pattern of trading rule returns and exchange rate intervention: intervention does not generate technical trading profits

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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. The data reject the hypothesis that intervention generates inefficiencies from which technical rules profit. In particular, high frequency data show that abnormally high trading rule returns precede German, Swiss and U.S. intervention. 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.

Keywords: Technical analysis; Trading rule; Intervention; Exchange rate; Central bank

JEL classification: G0; G14

1. Introduction

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

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exchange market (Sweeney, 1986; Levich and Thomas, 1993; Neely et al., 1997; Osler and Chang, 1999). 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 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 et al., 1999); and (3) official intervention in foreign exchange markets generates 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; Kritzman, 1989). 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] Further research extended this result. Szakmary and Mathur (1997) found that monthly trading rule returns were correlated with changes in reserves – a proxy for official 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. These findings further convinced many researchers that technical trading profits were generated by intervention (Martin, 2001).

No paper, however, has carefully considered whether the timing of intervention and returns supports the hypothesis that intervention generates trading rule profits. This study uses high-frequency trading rule returns and five intervention series from four central banks to investigate that issue. The timing of signals/returns around intervention and the direction of trading are inconsistent with the idea that intervention generates technical trading rule profits. In particular, high trading rule returns *precede* U.S., German and Swiss intervention and trading rules consistently trade contrary to the direction of intervention. While high 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 in this case. Rather, intervention is correlated with trading rule returns because monetary authorities intervene in response to short-term trends from which trading rules have recently profited.[2]

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[1]Davutyan and Pippenger (1989) explored similar issues with Canadian data from the 1950s.

[2]This does not, of course, mean that monetary authorities seek to minimize technical trading profits. Instead, authorities seem to dislike the trends themselves.

2. The data

This analysis uses five intervention series from four monetary authorities – Australia, Germany, Switzerland and the United States. The interventions of Australia, Germany and Switzerland were conducted in the respective national currencies (AUD, DEM, CHF) against the U.S. dollar (USD), while the U.S. data involve in-market transactions in the DEM/USD and Japanese yen/U.S. dollar (JPY/USD) markets.[3] Full summary statistics are available in the working paper but are omitted here for brevity.

To correspond with the U.S., German and Swiss intervention series, this paper uses 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. The daily exchange rate corresponding to the Australian intervention data was the AUD/USD rate collected by the Reserve Bank of Australia at 4:00 p.m. Eastern Australian Time, 0600 GMT.

The Bank for International Settlements (BIS) provided daily interest rate data, 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 et al. (1997) and Neely and Weller (2001); summary statistics are omitted for brevity.

The use of daily exchange rates almost inevitably leaves some ambiguity about the timing of 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. 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 sample length 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.[4] 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. For each intervention series, the maximum sample in which the intervention series, the daily exchange rate and the intraday exchange rates all exist was selected. The data were filtered to remove outliers. Sample lengths ranged from 10 years for the Swiss intervention in CHF/USD to 15 years, 6 months for the U.S. and German cases. Experiments and summary measures – omitted for brevity – show that the irregular nature of

[3] Intervention is defined narrowly to include only transactions, not other types of policies that affect exchange rates.

[4] 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.

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

For continuity with the previous literature, this paper follows LeBaron (1999) and examines the profitability of signals from a moving average (MA) 150 trading rule. 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.

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 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 excess return to switching back and forth between fully margined long and short positions in USD is approximated by $z_t r_t$. The variable z_t takes the values of $+1$ (-1) for a long (short) position in USD and r_t is defined as

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

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

$$r = \sum_{t=0}^{T-1} z_t r_t.^{5} \tag{3}$$

Panel A of Table 1 shows the mean annual return, standard deviation, t-statistic, trades-per-year and risk-adjusted returns from applying an MA 150 trading rule to each of the five samples. The rule makes positive returns in all five samples, ranging from 8.72% per annum for the JPY/USD from July 1983 to December 1998 to 2.44% for the AUD/USD from March 1985 through June 1999. The row

[5] 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. A reasonable adjustment for the transactions costs of a large trader (five basis points per round trip) would lower annual returns by 25 to 40 basis points, leaving them still well above zero.

Table 1
Daily trading rule returns conditional on removing periods 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	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
	ntrades	7.55	7.55	5.23	6.41	8.17
	P-value	0.01	0.00	0.00	0.05	0.14
	Sharpe	0.55	0.55	0.80	0.41	0.25
	α	6.09	6.09	8.59	5.07	2.75
Panel B: Remove $p(t)/p(t-1)$ when $I(t) \neq 0$						
	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
	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
	Sharpe	0.25	0.13	0.44	0.37	−0.34
	date 1	7/1/83	7/1/83	7/1/83	1/3/86	3/4/85
	date 2	12/31/98	12/31/98	12/30/98	12/29/95	6/30/99

Notes: The table shows the results of an MA 150 rule on daily foreign exchange rate data (Eq. (3)). 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 percentage return to the rule. *std* is the standard deviation of the daily percentage returns. *ntrades* is the number of trades per year. *t-stat* is the *t*-statistic for the null hypothesis that the mean annual return is zero. *P-value* is the bootstrapped *P*-value for the test that the mean return is zero. Low *P*-values reject the null hypothesis. *Sharpe* is the annualized Sharpe ratio. α is the estimate of the risk-adjusted annual return from a four-factor pricing model. See Eq. (4). *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 m/d/y format.

labeled *P*-value shows the probability – computed via bootstrap – that such returns would be produced 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.

The final rows of Panel A display two risk-adjusted-return measures, the Sharpe ratio and the constant from a linear factor model (α). The Sharpe ratio – the expected excess return per unit of risk for a zero-investment strategy – is the annual excess return to the trading rule over that excess return's annual standard deviation. A linear multifactor model 'explains' the return to the rule as compensation for exposure to risk factors. One may write the linear factor model for the return to the rule as:

$$z_t r_t = \alpha + \sum_{k=1}^{N} \beta_k X_{k,t} + \varepsilon_t \tag{4}$$

where $X_{k,t}$ is the kth risk factor at time t. The choice of risk factors is always arbitrary, but CAPM theory suggests that returns that are correlated with the market portfolio may impose undiversifiable risk and therefore have positive excess return. Thus the first three risk factors were the excess returns over riskless rates to the German Commerzbank index, the Japanese Nikkei index and the U.S. S&P 500 index. The fourth risk factor was the mean squared daily return over the previous five business days, a proxy for time-varying univariate risk. The linear factor models were estimated at the daily and monthly frequency by ordinary least squares to produce risk-adjusted returns (α).

Consistent with most of the previous literature on risk adjustment of foreign exchange trading rule returns, neither the Sharpe ratios nor any of the four linear factor models provide any evidence that the returns compensate the trading rules for bearing risk. The Sharpe ratios range from 0.25 to 0.8, comparing favorably with those from equity markets. The risk-adjusted returns (α) are close to the unadjusted returns. Analogous results at the monthly frequency – omitted for brevity – lead to similar conclusions. Risk adjustment does not reduce the technical returns significantly; unadjusted returns will be used in the rest of the paper.

3.2. Removing periods of official intervention

Panel B of Table 1 shows the results from LeBaron's (1999) procedure that removes returns from $t-1$ to t when there is intervention at t.[6] LeBaron's (1999) sample comprised in-market U.S. intervention in the DEM/USD and JPY/USD markets from 1979 through 1992. LeBaron showed that removing periods of U.S. intervention from the trading rule return series reduced the returns to insignificance. This has been interpreted as evidence that intervention caused those trading rule returns. 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 mean return is still a healthy and statistically significant 4.5%.

The row labeled Markov P-value shows the bootstrapped probability that

[6]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 $t-1$ to t, but only half of the U.S. business day.

randomly removing returns – assuming that intervention follows a Markov process – would lower the return as much as removing actual intervention observations. 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: the MA 150 rule has a 4.4% 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 Swiss intervention and a shorter sample. Therefore, the Markov P-values reject the hypothesis that randomly removing returns would lower the return as much as removing actual interventions.

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 to −2.27%. Strong results also are generated by removing Bundesbank intervention in the DEM/USD market from July 1983 through December 1998. Removing Bundesbank intervention periods reduces the annual return from 6.03 percent to only 1.28%.

Fig. 1 illustrates the predicted daily trading rule returns, with a one-standard error band, around days of intervention. Predicted returns were constructed by regressing daily trading rule returns on leads and lags of an indicator variable for non-zero intervention:

$$z_{t-1}r_{t-1} = a_0 + \sum_{j=-2}^{2} b_j I_{t+j} + \varepsilon_{t-1} \qquad (5)$$

where I_{t+j} is an indicator variable taking the value one if there is any intervention on day $t+j$. The regression coefficients $(\{a_0 + b_j\} | j = -2, -1, 0, 1, 2)$ 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 Fig. 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 17 for those cases. Similarly, the predicted return from t to $t+1$ coincides with the label 41, etc.[7] The vertical lines in each panel denote business hours for the intervening country.

On the whole, Table 1 and Fig. 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

[7]Twenty four hours after 1700 would be 41 in the notation of the figure.

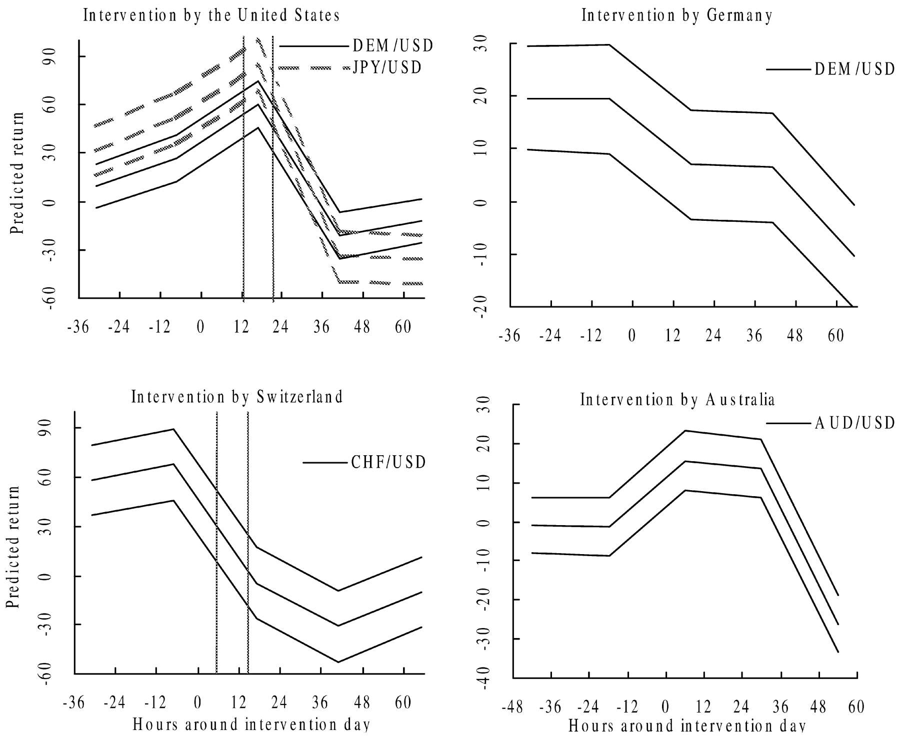

Fig. 1. Daily trading rule returns around periods of intervention. *Notes*: The figure depicts predicted daily backward-looking returns and a one-standard error confidence interval to an MA 150 rule around periods of intervention. The figures were obtained by regressing trading rule returns on leads and lags of intervention. The vertical lines depict business day hours 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.

and Mathur (1997) in multinational monthly data or by Saacke (1999) and Sapp (1999) in U.S. and German data.

4. Why might intervention be correlated with technical trading rule profits?

This section lays out two alternate explanations for the correlation between intervention and trading rule returns and develops testable hypotheses to discriminate between those explanations.

Explanation 1. *Intervention generates or amplifies patterns that trading rules detect and from which they profit.*

Explanation 2. *Intervention leans against the wind. That is, intervention reacts to recent trends in exchange rates from which trading rules profit.*

Although the mechanism by which intervention might generate profits to trend-following trading rules is not fully developed in the literature, one can reason out three possibilities. 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 the trading rule to trade with the central bank – when the central bank buys dollars, the trading rule also buys dollars. This story implies the following testable hypothesis:

TH (1.1). *Intervention precedes trading rule profits and trades in the same direction as the trading rule.*

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, if the trading rule does not switch positions during intervention, it can't take advantage of a delayed movement. That is, the data must show:

TH (1.2). *Intervention precedes trading rule profits, and the trading rule switches positions during or shortly after the intervention to trade against the intervention.*

The third story is that expectations of future intervention (e.g. USD purchases) cause a sustained appreciation of the USD from which the trend-following trader profits.[8] This implies testable hypothesis (1.3):

TH (1.3). *Intervention follows trading rule profits and trades with the trading rule.*

On the other hand, if Explanation (2) is correct – intervention is correlated with technical trading profits because it reacts to the same strong trends in exchange rates from which trend following rules profit – then one might expect the following:

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[8] Although intervention is predictable to a certain extent, the author's prior is that expectations of intervention are unlikely to induce such substantial changes in exchange rates.

TH (2.1). *Intervention follows or is coincident with trading rule returns. Exchange rate changes predict intervention. Intervention trades against the trend-following rule.*

To summarize, if intervention generates or amplifies trading rule returns, then either TH (1.1), TH (1.2) or TH (1.3) must be true. If, instead, intervention reacts to trends from which trading rules profit, then TH (2.1) will be true.

A natural procedure to determine the relationship between trading rule returns and central bank intervention would be to write down reduced form equations for trading rule returns and intervention, to make identifying assumptions, to estimate the model and to derive the implied structural relationship between intervention and trading rule returns. While this procedure is natural and attractive, it is not necessary to investigate the issues of this paper and it entails making heroic assumptions about the timing of intervention and identification. For example, the first choice in such a procedure would be to match up intervention observations with contemporaneous observations of trading rule returns. Because the exact timing of intervention is uncertain, however, one cannot match intervention one-for-one to high-frequency return data. On the other hand, the use of daily data would ignore information on the high-frequency timing of returns and intervention. Further, the possibility of high frequency feedback between trading rule returns and intervention precludes any obvious way to identify the contemporaneous relationship.

To determine whether intervention generates trading rule returns, the next section characterizes the timing of high frequency returns, signals and intervention, and examines with which testable hypotheses such patterns are consistent.

5. Intraday results

5.1. Results with intraday data

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

$$r_{i,t} = \ln S_{i+1,t} - \ln S_{i,t} \tag{6}$$

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.[9] The return during a period is 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.

Table 2 displays the trading rule statistics from signed daily returns, constructed from intraday exchange rates. Comparing Table 2 with Table 1 shows that including or excluding interest differentials makes little difference to the results. All of the annualized intraday returns, excluding interest rate differentials, are within 75 basis points of the interest-adjusted daily results in Table 1. The bootstrapped P-values for the null of zero return are only slightly higher than those in Table 1. The largest such statistics are 0.07 and 0.17 for the Swiss and Australian cases, respectively. The similarity between Tables 1 and 2 is consistent

Table 2
Daily trading rule returns with intraday data

Monetary Authority exchange rate		United States DEM/USD	Germany DEM/USD	United States JPY/USD	Switzerland CHF/USD	Australia 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
	t-stat	2.15	2.15	3.01	1.47	0.93
	ntrades	7.55	7.55	5.23	6.41	8.17
	P-value	0.02	0.02	0.00	0.07	0.17
	Sharpe	0.55	0.55	0.76	0.47	0.25
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
	t-stat	0.99	0.59	1.62	1.37	−1.30
	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
	Sharpe	0.25	0.15	0.41	0.43	−0.34
	date 1	7/1/83	7/1/83	7/1/83	1/3/86	3/4/85
	date 2	12/31/98	12/31/98	12/30/98	12/29/95	6/30/99

Notes: See the notes to Table 1.

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

with LeBaron's (1999) finding that the correlation between trading rule returns and intervention is robust to the treatment of interest differentials.

As in Table 1, 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% annual return, whereas removing days of Australian intervention from the AUD/USD series reduces the annualized return to -2.27%. 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 randomly removing returns would lower the mean as much as removing actual intervention.

5.2. The temporal pattern of intraday returns and intervention

To characterize the high-frequency temporal pattern of trading rule returns and intervention, a procedure similar to that used to create Fig. 1 is followed. Intraday trading rule returns – where periods are hours long rather than one day – are regressed on leads and lags of intervention signals. That is, returns around intervention are predicted by fitted values from the following regression:

$$z_{i,t} r_{i,t} = a_{i,0} + \sum_{j=-2}^{2} b_{i,j} I_{t+j} + \varepsilon_{i,t} \tag{7}$$

where $z_{i,t}$ is the $\{-1,1\}$ signal from the MA 150 rule associated with the ith 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 jth lag of the indicator variable for non-zero intervention at t.

Panel A of Fig. 2 displays the backward-looking predicted intraday returns in the five business days around intervention ($\{a_{i,0} + b_{i,j}\}|j = -2, -1, 0, 1, 2$), as well as one-standard-error bands. The estimated $a_{i,0}$ coefficients were very small. To facilitate the discernment of patterns in the noisy data, Panel B shows a backward-looking, 24-h 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 2 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 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

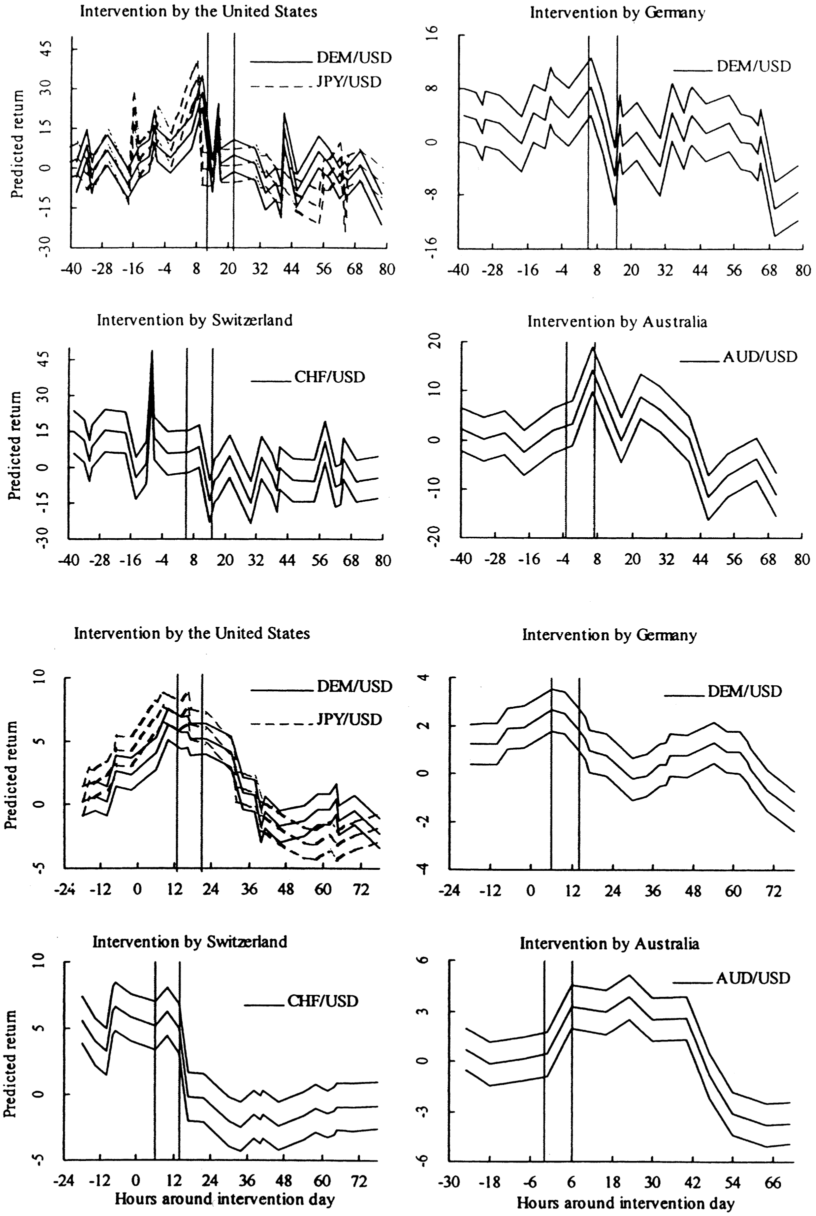

Fig. 2. Intraday trading rule returns around periods of intervention. Notes: The top panel depicts backward-looking predicted intraday returns to an MA 150 trading rule around periods of intervention with a one-standard error band. The bottom panel shows a backward-looking, 24-h moving average of those predicted returns with its error band. Vertical lines depict business day hours in the intervening country. The horizontal axis shows hours before (negative) and after (positive) midnight on the day of intervention in GMT.

Bank intervened for the first time at 1400 GMT during joint intervention with the Federal Reserve. 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.[10] 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).

Fig. 2 is consistent with Fig. 1 and Tables 1 and 2 in that the backward-looking trading rule returns are usually high from −700 to 1700 GMT on the day of interventions for the U.S., Swiss, and German cases. Fig. 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 precede the business hours during which most intervention would be carried out.[11] The highest returns are finished by 0800 GMT for the U.S. and German cases and by 1000 GMT for the Swiss case.

5.3. Morning-to-morning and business day results

One can quantify how much of the abnormal returns in Fig. 2 likely 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 2. Panel A of Table 3 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 2. Panel B shows that removing observations in the 24 hours prior to the beginning of the business day of intervention reduces the mean returns substantially. But, these high returns almost surely precede intervention and therefore could not plausibly have been caused by intervention.[12] 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%) that are statistically significant at the 10% level. These results are consistent with hypothesis (2.1);

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

[11] 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 2 days of another intervention. With 70 to 95% fewer observations, results for the U.S. and Swiss cases were consistent with Fig. 2; those for Germany showed no clear pattern and those for Australia were inconsistent with results shown in Fig. 2.

[12] This statement assumes that expectations of intervention are unlikely to systematically create significant changes in exchange rates.

Table 3
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						
	mean	5.87	5.89	8.28	5.91	2.40
	P-value	0.02	0.01	0.01	0.05	0.20
Panel B: Remove $p(t)/p(t-1)$ when $I(t) \neq 0$						
	mean	2.28	0.05	3.69	2.95	−0.65
	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 $I(t)/=0$						
	mean	4.23	2.18	6.02	6.04	−2.65
	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						
	mean	3.32	1.95	5.75	3.56	1.32
	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						
	mean	3.90	3.31	6.99	5.91	−0.30
	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	7/1/83	7/1/83	7/1/83	1/3/86	3/4/85
	date 2	12/31/98	12/31/98	12/30/98	12/29/95	6/30/99

Notes: The table provides statistics on returns calculated from morning-to-morning or morning-to-evening, around periods of intervention. Morning-to-evening (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. Local times would be −5, +1, −5, +1 and +10 h from the GMT figures, respectively. The notes to Table 1 define *mean, P-value,* and *Markov-P*. Panel A shows the results for all observations. Panel B removes the returns in the 24 h prior to the beginning of the morning observation when there is intervention. Panel C removes the returns in the 24 h 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.

intervention responds to short-term trends in the market but does not generate trading rule returns.

The German intraday results from Panel C of Table 3 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%. However, Fig. 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% 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. 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. The JPY/USD trading rule returns a hefty 6.99%, for example, after excluding business days of U.S. intervention.

Fig. 2 and Table 3 show that for the U.S., Swiss, and German cases, most abnormally high returns precede business hours and thus precede intervention. This timing is consistent with either testable hypothesis (1.3) or (2.1). In other words, the correlation between intervention and trading rule returns probably results from fulfilled expectations of future intervention or monetary authorities 'leaning against the wind' of exchange rate trends. For the Australian case, however, the timing evidence is consistent with hypotheses (1.1), (1.2) and (2.1) as intervention precedes or is contemporaneous with high returns. The next section examines the timing and direction of trading and intervention to determine with which hypotheses they are consistent.

5.4. The timing and direction of intervention and trading rule signals

Hypotheses (1.1), (1.2) and (1.3) all require the trading rule either to trade with intervention – i.e. to buy USD when the central bank buys USD – or to switch positions to trade against the central bank. In contrast, hypothesis (2.1) implies that intervention trades contrary to technical trading signals. To investigate the facts on the timing and direction of intervention and trading rule signals, Table 4 shows that the MA 150 rule consistently (typically more than 80% of the time) trades against the position taken by central banks in periods around intervention. Thus, the timing and direction of trading signals around intervention rejects hypotheses (1.1), (1.2) and (1.3) for each case; intervention does not generate or amplify trading rule profits. Instead, this evidence is consistent with hypothesis

Table 4
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 2 days prior to intervention to 2 days after intervention. For example, the first row, second column shows that MA 150 traders were purchasing (selling) dollars only 5% 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.

(2.1), that central bank intervention responds to strong trends in exchange rates. The next section formally investigates intervention reaction functions.

5.5. Under what conditions do these monetary authorities 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 want 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 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 $t-1$. (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% 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:

$$\ln(S_t) - \ln(P_t^*) + \ln(P_t) = \mu + \beta t + \varepsilon_t \tag{8}$$

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.[13] A friction model permits the dependent variable – intervention – to be insensitive to changes in the independent variables over some range of values.

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

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:

$$L(\gamma_1,\gamma_2,\beta,\sigma|I_t,x_t) = \prod_{t\in T_1}\frac{1}{\sigma}\phi\left(\frac{I_t+\gamma_1-\beta' x_t}{\sigma}\right) \times \prod_{r\in T_2}\left[\Phi\left(\frac{\gamma_2-\beta' x_t}{\sigma}\right)-\Phi\left(\frac{\gamma_1-\beta' x_t}{\sigma}\right)\right] \times \prod_{t\in T_3}\frac{1}{\sigma}\phi\left(\frac{I_t+\gamma_2-\beta' x_t}{\sigma}\right) \quad (9)$$

where I_t is intervention at time t, γ_1 (<0) is the lower bound on insensitivity for changes in the linear combination of explanatory variables ($\beta' x_t$) to affect I_t, γ_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-hours cumulated returns and the deviation of the exchange rate from fundamentals were permitted for each intervention series; the models were estimated by maximum likelihood, subject to the constraint that the estimated model be stationary.[14] The best model was selected by the Schwarz criterion (SC).

Table 5 displays the coefficients from the best models as well as the results of two likelihood ratio (LR) tests. Consistent with the autocorrelation found in the summary statistics, the coefficients on lagged intervention (I1–I3) are generally positive. Coefficients on lagged returns (R1–R4) are negative – indicating leaning-against-the-wind behavior. The coefficient on the exchange rate deviation (XRD) is also negative in each case, meaning that monetary authorities tend to buy (sell) dollars when the value of the dollar is below (above) its purchasing-power-parity fundamental measure. The restriction that the coefficient(s) on the lag(s) of the exchange rate return are jointly zero is overwhelmingly rejected by a likelihood ratio test in each case. Intervention leans against the wind.[15] The only case for which the LR test fails to reject that the coefficient on the exchange rate deviation is zero is that of the AUD/USD, for which the coefficient is correctly signed but insignificant.

The reaction function evidence indicates that intervention leans against the wind and is conducted against misalignment. The leaning-against-the wind behavior is inconsistent with hypotheses (1.1), (1.2) and (1.3) but consistent with Explanation (2)/hypothesis (2.1). Intervention reacts to counter recent trends in exchange rates from which trading rules profit.

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

[15] Although intervention leans against the wind and loses money in the short run, Neely (1998) shows that U.S. foreign exchange intervention has been profitable in the long run.

Table 5
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
γ_1 (s.e.)	−0.59	(0.03)	−0.28	(0.01)	−0.59	(0.04)	−0.29	(0.03)	−0.11	NA
γ_2 (s.e.)	0.65	(0.04)	0.40	(0.02)	0.64	(0.04)	0.49	(0.04)	0.06	NA
LR test 1, *P*-value	52.50	(0.00)	433.61	(0.00)	83.00	(0.00)	88.15	(0.00)	153.52	(0.00)
LR test 2, *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 (see Eq. (9)). The best models were selected from maximal lag lengths of five lags of intervention and five lags of returns by the Schwarz criterion. Coefficients on lags of intervention are labeled I1 to I5, those on the lagged return variable as R1 to R4 and the coefficient on the exchange rate deviation as XRD. σ denotes the estimated standard deviation and γ_1 and γ_2 denote the estimated inactivity boundaries. NA indicates that standard errors were unavailable as the Hessian matrix was nearly singular. The last two rows show the likelihood ratio test statistics and *P*-values 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.

A common problem in estimating time series relations, such as reaction functions, is structural instability. 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. 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.

6. 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. Many have interpreted recently found correlations between intervention and trading rule returns as confirming this suspicion. 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, as well as in Australian and Swiss data. For the U.S., Swiss, and German 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.

The explanation for the puzzle of technical trading profitability might lie in the way that information is transmitted through the microstructure of the foreign exchange market (Treynor and Ferguson, 1985; Brown and Jennings, 1989; Banerjee, 1992). Recently, Evans and Lyons (1999, 2000) have used an interdealer data set to examine several features of the data including the following: (1) imperfect substitutability of international assets; (2) signaling; (3) and a lower bound on the price impact of trades. In addition, they find a strong relation between order flow and exchange rate changes. In another line of attack, Naranjo and Nimalendran (2000) relate the adverse selection component of the bid-ask spread to the variance of unexpected intervention. Of course, this implies that unexpected intervention may reduce real-world trading profits by widening the spread.

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