Persistent Profitability of Technical Analysis on Foreign Exchange Markets? *

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There is no question that professional participants in foreign exchange markets often employ technical analysis to make investment decisions (e.g. Frankel and Froot 1990). Although the popularity of this instrument changes over time, it was already widespread 15 or 20 years ago (e.g. Goodman 1979) and it is nowadays used by the majority of professionals for their short-term decisions (Taylor and Allen 1992). Obviously, this way of analyzing foreign exchange markets has not been identified as useless by the process of market competition. For equating the participants' objective with earning excess returns, the use of technical analysis seems to be persistently profitable.

The result of this analysis questions the proposition of efficient foreign exchange markets that would rule out the profitable use of generally available information on which technical analysis is based. The impression of persistence heightens this challenging problem, because it touches a basic behavioral assumption of functioning markets: that rational participants are learning. Either the use of technical analysis produces no profits, in which case most actors do not seem to learn efficiently from failures of technical analysis, or its use is profitable, and the actors do not seem to learn from success; otherwise "arbitrage" should eliminate profit opportunities.

In investigating this puzzle we will first analyze existing literature with two aims: does a broader overview verify the notion of the "persistent profitability" of technical analysis and what are the requirements to pursue earlier studies with more recent data in a methodologically convincing way? Based on these considerations, we convey our empirical analysis of persistent profitability by extending a standard approach to a later period of time. Going further, we want to shed new light on this puzzle by imitating the situation in which the large currency speculators, i.e. foreign exchange dealers and international portfolio managers, make their decisions. This perspective suggests a different form of risk consideration.

The outcome of our research partly confirms the impression of persistent profitability of technical analysis on foreign exchange markets. This holds true for the literature survey as well as for our own empirical investigation, following a standard approach, and does not seem to be very sensitive to some methodological modifications. So far the puzzle has been confirmed. But one element for our understanding is provided by the proposed consideration of risk perception by professionals. While technical analysis does not seem to be excessively risky from a performance-oriented long-term point of view, our study hints at enormous risks from the short-term perspective of professional speculators. The latter may show a direction for a better understanding of the economic problem of persistent profitability.

In the following, Section I offers a short survey of the literature as a basis for our investigations. In Section II we give the reasons for the data chosen and methodology, examining 43 variants of technical analysis rules which cover the three most important currencies' relations versus the D-Mark for the period from January 1981 to December 1991, as well as two sub-periods. The results, showing profitability but also enormous heterogeneity over time and with regard to different measures of risk, are presented in Section III. In Section IV we discuss various approaches explaining our empirical results.

I. Evaluation of previous studies

The numerous studies on the profitability of technical analysis by testing for surplus yields in comparison to a benchmark can be divided into three phases: there are front-running studies from the 1960s and 1970s hampered by data and methodology problems, followed by the development of standardized studies in the 1980s and, most recently, by a variety of new approaches.

The older studies from the 1960s and 1970s already indicated some profitability of technical analysis (Poole 1967a, 1967b, Dooley and Shafer 1976, Logue and Sweeney 1977, Logue, Sweeney and Willett 1978, Cornell and Dietrich 1978).[1] However, these studies are necessarily limited as to the time series base in that they were either based on old data or on data from the Bretton Woods fixed exchange-rate system or time periods covering only two to three years. These data restrictions do not allow for reasonable conclusions regarding the question of persistence; furthermore, various methodological weaknesses can be criticized (see e.g. Sweeney 1986, p. 163).

Compared to these older investigations, the four studies of the second phase, summarized in Dooley and Shafer (1983), Sweeney (1986), Schulmeister (1987) and Leoni (1989), are based on longer time periods of between seven and thirteen years.[2] They establish, as did the studies in the 1970s, a (sometimes limited) superiority in the use of technical analysis compared to the buy-&-hold strategy. Common to all these studies is the investigation of a variety of quantitative technical analysis (instead of qualitative methods, i.e. chartism) applied to daily spot market data for several sub-periods.

With regard to the interesting problem of persisting profitability, these studies have some advantages. The longer time periods examined reduce the probability that the time series reflects accidental regularities which would not exist in a sufficiently long observation. Furthermore, out-of-sample measurement is necessary in accordance

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[1] Additionally, Goodman (1979) evaluates ten forecasting services and comes to the conclusion that services based on technical analysis are superior to those based on fundamental (economic) models in the time period from January 1976 to June 1978 and that most of them also beat the buy-&-hold alternatives.

[2] These studies are often considered in the literature, for example by Levich (1989, p. 46) or Levich and Thomas (1993, pp. 454ff.), who mention them all except the study by Leoni (1989).

with the *ex ante* application of technical rules in the real world, whereas profitable *ex post* optimization can be carried out on the basis of almost any time series. Swap and transaction costs as well as the risk taken should be considered in the profitability calculations in order to attain the most realistic results possible. Lastly, the rules of technical analysis under investigation are quite simple and therefore well-known to those interested.

For some further characteristics of the individual studies, see the overview in Table 1. Here, very common rules of technical analysis are tested, the mechanics of which are explained for a purchase recommendation (the sell recommendation can be derived analogously):

— Filter rule: buy if the rate is x percent above the last low.

— Oscillator (moving averages): buy if the shorter-term average (sometimes simply the current rate) exceeds the longer-term average.

— Momentum: buy if the current rate is higher than that of the x-th day previously.

The main result of the earliest study – by Dooley and Shafer (1983) – is that the profitability of definite technical analysis rules holds even over a period of more than eight years and does not disappear or decline over time.

Sweeney (1986) established that filter rules which were significantly profitable in his first period were only partly so in the following period. Nevertheless, retaining all the significantly profitable rules from the first period in the second period would still bring profits (p. 177). The update and extension of this study in Surajas and Sweeney (1992) for the period July 1974 to May 1986 confirm the main results.

Schulmeister (1987 and 1988) examined – although only for the DM/US$ rate – the longest and most recent time period. A 2% filter produces the best result of all tested filter rules. However, using additional technical rules, certain oscillator, momentum and mixed (O+M combined) rules are considerably better.

Lastly in Leoni (1989, pp. 308ff.), many technical strategies are indeed more profitable than that of buy-&-hold, but their results are very unstable and thus *ex ante* practically ineffective. The comparatively weak results of this study are probably due to its conception.

TABLE 1

CHARACTERISTICS OF PREVIOUS STUDIES

Criteria / Study	Period under investigation	Frequency of data	Currencies considered	Rules of technical analysis	Long/Short positions	Swap-costs	Transaction-costs per round trip	Out-of-sample periods	Risk adjustment
Dooley/Shafer (1983)	3/73-11/81	daily	9 vs. US$	7 Filters	1/s	+	+	09/75-11/81 09/75-10/78 10/78-11/81	–
Sweeney (1986)	4/73-12/80	daily	10 vs. US$	7 Filters	1	–*	–*	last 2/3 of total period	risk premium calculated by uncovered interest rate parity
Schulmeister (1987)	4/73-9/86	daily	DM/US$	9 Filters 9 Oscillators 5 Momentums 7 O+M combined	1/s	–*	–*	no explicit analysis, but several sub-period	(T-statistics)
Leoni (1989)	74-83	daily weekly monthly	8 vs. DM	6 Filters 6 Oscillators 6 Momentums 6 RST**	1	–	+	79-83	Sharpe ratio
This paper for comparison (see Sections II-III)	1/81-12/91	daily	DM/US$ DM/yen DM/pound	33 Oscillators 10 Momentums	1/s	+	+	1/86-12/91	Sharpe ratio Gauß-Test

* Arguments are given for the non-decisive non-consideration.
** Not on a daily basis.

On the one hand, intra-European exchange rates with small volatility are predominantly tested, which raises the probability of "false" signals. On the other hand, the declared yields are surprisingly low, which is the result of unusually highly set transaction costs.[3]

In addition to these, there is now a third phase of work in progress which consists of two directions for analyzing the profitability of technical analysis. The first also investigates quantitative rules of technical analysis but cover either monthly data (Leithner and Spahn 1991) or use the futures instead of the spot market (Lukac et al. 1988, Taylor 1992, Levich and Thomas 1993) or analyze foreign exchange portfolios (Pictet et al. 1992, Surajas and Sweeney 1992). All of these studies conclude that there is a remarkable profitability of technical analysis; the case of persistence is especially stressed by Surajas and Sweeney (1992) and Levich and Thomas (1993).

A possible criticism of this type of study may be that the technical analysis rules are arbitrarily chosen. Therefore – as a second direction of study – Curcio and Goodhart (1991 and 1992), following Allen and Taylor (1990), report on experimental markets with market professionals and students (1991) and on investigations with high-frequency data on publicly maintained so-called support and resistance levels (1992). Their second study offers evidence to support the hypothesis of profitable technical analysis, whereas the other results provide no clear-cut answer. In the same vein De Grauwe and Decupere (1992) search for psychological barriers in the foreign exchange markets as they are often seen by people using technical analysis. They find some evidence of barriers for the yen/US$ market but not for DM/US$ or reverse quotations.

Conclusions can be summarized as follows:

– Almost all these studies support the theory of profitable currency speculation on the basis of (quantitative) technical analysis rules. This holds independently of the method of risk adjustment or significance measurement.

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[3] For example, Leoni (1989, p. 505) states that the annual yield of the 10-momentum for the DM/US$ rate in the period 1979-83 to be only 2.56%, whereas Schulmeister (1987, Table 9) gives more than 10%. Because Leoni (1989, p. 305) apparently chose the spread published in the newspapers, which explains most of the difference in yields, the transaction costs correspond to the private customer level but are above the level relevant here for professionals (interbank operations) by a factor of approximately 10.

– In comparison with oscillators and momentums, filter rules are mostly a sub-optimal and unusual procedure (Cornell and Dietrich 1978, p. 116; Lukac et al. 1988, p. 627; Sweeney 1991, p. 251; Surajas and Sweeney 1992).

– The out-of-sample measuring tends to show temporary instability in the rules' relative advantages.

– Transaction costs diminish yields in a way that can determine the profitability of technical analysis. Swap costs are sometimes neglected because they do not have to dominate the decision (see Sweeney 1986, Schulmeister 1987, p. 18).

– Various measures of risk used do not indicate that the attainable surplus yields should be considered to be a compensation for unusually high risks (Cornell and Dietrich 1978, Sweeney 1986, Schulmeister 1987, Leoni 1989, Taylor 1992, Levich and Thomas 1993).

II. Data and methods

To investigate the problem of persistence, our examination of profitability follows the methods of the "standard" studies in the 1980s. We concentrate on the most important market segment, i.e. spot (and forward) market transactions on a daily basis and cover only well-known technical analysis rules. It goes beyond the four similarly conceptualised studies just discussed (see Table 1), because the period of investigation is more recent, the most important currencies from a German viewpoint are included, variants of customary technical analysis rules are broadly covered and also all of the above-mentioned methodological guidelines are fulfilled. In particular, the following data and methods are used.

The data base covers an 11 year-long period from January 1981 to December 1991. Viewed from the Deutsche Mark, the three most important currencies with regards to trading volume are examined: the US dollar, yen and pound sterling (BIS 1993). The daily spot exchange rates, 2869 data each, are taken from Frankfurt fixing (source: Datastream). The London Euromarket three-month interest rates are used to calculate the swap costs (source: Datastream). The

interest rates are approximations due to data availability. However, the money market rates for various maturities are usually so close to each other that probably no relevant error arises from this simplification.

The level of transaction costs can, in accordance with usual interbank quotations, be set at 0.0008 DM for 1 US$ or 0.0017 DM for 100 yen and 0.003 DM for one pound. With the dollar rate at 2 DM, for example, this is equivalent to costs of four parts per thousand for a round trip and thus per signal.[4] This level is slightly below the figures used by Sweeney (1986) and Schulmeister (1987) reflecting the declining spreads in the foreign exchange markets. The transaction costs assumed are, however, markedly higher than for futures market transactions (Levich and Thomas 1993).

To avoid an *ex post* selection bias, from the diversity of technical analysis rules, only oscillator and momentum rules are chosen, which were also widely used in 1985 and which proved at the time to have been more profitable than filter rules. In order to avoid random results, 33 variants of the oscillator and 10 variants of the momentum rules are examined.[5] The selection of the tested variants, with "round" values preferred, from the incomparably larger universe of conceivable possibilities is in the last place arbitrary. The selection is further aimed at achieving an aspired broad coverage from more sensitive to more sluggish variants and some systematic combination of the same short-term and long-term averages for the oscillator.

These technical analysis rules were examined for three periods. The "support" period 1/1981-12/1985 serves to simulate an *ex ante* decision on the advantages of competing technical rules, which could then be used in an out-of-sample period from 1/1986-12/1991. To control the *ex post* optimality, the whole time period 1/1981-12/1991 is also considered.

Under these prevailing conditions, a speculative currency strategy is simulated which decides on investing either long or short in foreign currency. Due to the purely speculative character of this

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[4] The transaction costs are twice as high per signal as for the pure hedging strategy. This is because not only is the starting position closed but also the opposite one is also directly newly opened.

[5] These were the following oscillators (units are days): 2/10, 2/20, 2/25, 2/30, 2/35, 2/40, 4/8, 4/10, 4/20, 4/25, 4/30, 4/35, 4/40, 5/10, 5/20, 5/25, 5/30, 5/35, 5/40, 6/10, 6/20, 6/25, 6/30, 6/35, 6/40, 8/20, 8/30, 8/40, 8/50, 10/20, 10/30, 10/40, 10/50 and the momentums: 5, 8, 10, 12, 15, 20, 25, 30, 35, 40.

strategy, opportunities on expected rising and falling foreign exchange rates may be exploited through the appropriate holding of positions, whereas hedging models (examples are Sweeney 1986 or Leoni 1989) only consider the occasional covering of foreign exchange assets. The latter thus aim to avoid losses from devaluating foreign currency but sacrifice the opportunity of profiting from an exchange-rate decline with a short position in foreign currency.

The profitability calculation, assuming per signal an investment of 1 US$, 1 pound or 100 yen, takes three elements into account: the difference between the exchange rates $(e_{t1} - e_{t0})$, the interest differential over the time of investment

$$e_{t1} \cdot (\text{fraction of the year}) \cdot (i^* - i)$$

i^* being the foreign interest rate, and the transaction costs per signal (c). This gives the following profit in Deutsche Mark for a single signal to buy foreign currency (i.e. a long position) and for a single signal to sell foreign currency (i.e. a short position) respectively:

$$(1) \qquad p \text{ long} = (e_{t1} - e_{t0}) + \left[e_{t1} \; \frac{\Delta t}{m} \; (i^* - i) \right] - c$$

$$(2) \qquad p \text{ short} = (e_{t0} - e_{t1}) + \left[e_{t1} \; \frac{\Delta t}{m} \; (i - i^*) \right] - c$$

where $\Delta t := t_1 - t_0$ and m denotes the number of days of the respective year for which exchange-rate data are available. The profit over a certain period of time *(p spec)* is calculated by adding the DM results per (buy or sell) signal within that period, plus adding the DM results for the sub-periods at the beginning and end of the relevant total period not covered by the already measured signals. This means for the possible sub-periods that e_{t0} and/or e_{t1} are not defined by signals.

Profits from technical analysis rules can be compared to those from a passive buy-&-hold strategy considered as an investment in the particular currency, acknowledging the interest differential to Deutsche Mark but neglecting transaction costs $(c=0)$. In our case, there is a profit from following the buy-&-hold strategy over the

whole time period for each of the three foreign currencies. This results on average in a disadvantage for the technical analysis strategy and makes the test criterion more difficult to pass.[6]

To compare speculative strategies with that of buy-&-hold, the profit is always calculated for periods of one month (k), assuming that the evaluation periods are of roughly that length. This seems to be quite a realistic time horizon for professional speculation in foreign exchange markets, being below the time horizon of portfolio managers but above that of foreign exchange dealers. Thus 132 "signals" for buy-&-hold are given in the entire period of 11 years.

$$(3) \qquad p^n \text{ buy-\&-hold} = \sum_{k=1}^{n} \left\{ (e_{t1} - e_{t0}) + \left[e_{t1} \frac{1}{12} (i^* - i) \right] \right\}$$

The profit formula for speculative strategies (p^n spec) is accordingly a month-by-month calculation of the sequence of alternating buy and sell signals:

$$(4) \qquad p^n \text{ spec} = \sum_{k=1}^{n} p \text{ spec}$$

As risk adjustment we have chosen the Sharpe (reward-to-variability) ratio, which is the ratio of the portfolio's average excess return (portfolio return less the risk-free rate) to the standard deviation of the portfolio returns (Sharpe and Alexander 1990, pp. 750ff.). Because the interest differential of money market rates covers the risk-free rate, the calculated average return per month (r), i.e. the mean, will in effect be divided by the standard deviation (s):

$$(5) \qquad \text{Sharpe ratio} = \frac{r}{s}$$

The advantage of this yardstick is its applicability to one-asset portfolios and the avoidance of any discussion about unknown time-

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[6] Exact figures are given in Tables 2-4.

varying risk premia.[7] Therefore, the Sharpe ratio seems to provide an acceptable risk adjustment.

However, from the viewpoint of imitating the decision-making of professionals, there may be a major disadvantage. The Sharpe ratio fits institutional circumstances, where results are evaluated at the end of a long-term period, in our case stretching over years. But this does not usually reflect the situation in reality. Instead, portfolio managers as well as foreign exchange dealers are evaluated at short time intervals against a buy-&-hold strategy benchmark. Thus, they might be unlucky by "beating" a Sharpe ratio benchmark via distinct – and almost necessarily partly disadvantageous – performance deviations against a buy-&-hold strategy over certain time intervals.

Therefore, as an explorative approach to catch the form of risk perception discussed above, we suggest the approximative Gauß-test, a form of T-test. Its robust statistical properties are favorable, especially in that it does not presume a normal distribution of the summands. This measurement concentrates on the mean of differences in profits ($Z_k := P_k \text{ spec} - P_k \text{ buy-\&-hold}$) over n months. Superiority of technical analysis is shown by a significant value of t:

$$(6) \qquad t = \frac{\bar{z}}{\sqrt{\dfrac{1}{n-1} \sum_{k=1}^{n} (z_k - \bar{z})^2}} \sqrt{n}$$

An economic interpretation of t can neglect $\sqrt{n}$ and concentrate on the two remaining factors, an understanding of which is related to the Sharpe ratio. The sign $\bar{z}$ indicates whether technical analysis gives a higher profit than buy-&-hold. The denominator, giving the standard deviation of z, indicates the extent to which the

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[7] As another method to adjust profits for risk, Sweeney (1986) explicitly derives a measure from the CAPM, in which the risk to be compensated is seen as holding foreign currency positions. The compensation is represented by the risk premium, which is assumed to be constant. Ultimately this leads to the testing of the combined hypothesis of no-profit speculation and a constant risk premium. Sweeney sees empirical refutation of this hypothesis as support for the profitability of technical rules, whereas others may interpret the same fact as support for the existence of time-variable risk premia. Sweeney (1986, p. 180; 1991, pp. 255-265) argues further in support of the use of constant risk premia with the unconvincing empirical results of tests for time-variable risk premia (see Froot and Frankel 1989). Because this conclusion is not compelling, the consensus at the moment seems to be that the problem has not been conclusively solved.

profits of the technical analysis rule deviate from buy-&-hold. The smaller the profit advantage of technical analysis, and thus the more important the deviations, the smaller t becomes which detracts from a significant advantage. We decided to take the common 95% confidence interval as a level which might give the investors sufficient security.

III. Results of the empirical analysis

The arithmetical results of the study contain two parts. Firstly, those which rely on the methodology of the 1980s standard studies, but use more recent time series and a somewhat different coverage by concentrating on the Deutsche Mark and certain forms of technical analysis. Later, additional considerations regarding the risk-inhibited are introduced, examining the stability of superior technical analysis rules over time and providing some calculations aiming to cover the short-term perspective of professional speculators.

In this section, the results are presented in a sequence, starting with simple profitability and adding further aspects to the analysis from that point on. Thus, let us consider the profits alone and neglect both the buy-&-hold benchmark and risk (as in Dooley and Shafer 1983). In this case, technical analysis seems to be persistently profitable (see Table 2, column 3). Of the 129 combinations over three exchange rates and 43 oscillators and momentums, 129 rules in the support period are profitable, as are 125 in the out-of-sample period and 129 in the entire period.

The picture becomes slightly worse when buy-&-hold is chosen as a benchmark (as in Schulmeister 1987), because the interest advantages of foreign currencies compared to the DM are not fully compensated for by their devaluation. This has the same effect as demanding a minimum profit instead of an indetermined profit only. Table 2, column 2 shows the figures for the two sub-periods as well as for the complete period. Whereas the profitability of technical analysis for the US dollar and the yen improves in the second sub-period compared to the first, measured by the share of successful rules, it deteriorates for the pound. If viewed from the perspective of an investor, who at the end of 1985 might have decided to apply

TABLE 2

THE SUPERIORITY OF TECHNICAL ANALYSIS COMPARED TO DIFFERENT BENCHMARKS

Currencies	Period	Total no. of cases	Cases of technical analysis superiority							
			(1) Sharpe ratio compared to B&H		(2) Profits compared to B&H		(3) Profits only		(4) Significant profits compared to B&H	
			No.	%	No.	%	No.	%	No.	%
US$	1.81 - 12.85	43	33	77	34	79	43	100	0	0
	1.86 - 12.91	43	42	98	43	100	42	98	28	65
	1.81 - 12.91	43	43	100	43	100	43	100	20	47
Yen	1.81 - 12.85	43	35	81	31	72	43	100	0	0
	1.86 - 12.91	43	43	100	43	100	43	100	8	19
	1.81 - 12.91	43	43	100	43	100	43	100	2	5
Pound	1.81 - 12.85	43	43	100	43	100	43	100	2	5
	1.86 - 12.91	43	24	56	22	51	40	93	0	0
	1.81 - 12.91	43	43	100	43	100	43	100	2	5
All	1.81 - 12.85 (1)	129	111	86	108	84	129	100	2	2
	1.86 - 12.91 (2)	129	109	84	108	84	125	97	36	28
	1.81 - 12.91	129	129	100	129	100	129	100	24	19
	(1) + (2)	258	220	85	216	84	254	98	38	15

technical analysis only to the most promising currency of the support period, i.e. the pound, he would have been very surprised. By a random selection of the employed technical rules he had a 51% chance of beating the profits of a simple buy-&-hold strategy. Including the two other currencies, this is of course the most pessimistic case, but it warns investors about prolonging any historic profits into the future.

As a next step, risk is considered by applying the Sharpe ratio (as in Leoni 1989). Compared to the pure profit measurement versus buy-&-hold, the picture is quite similar (see Table 2, column 1). The biggest difference is marked by technical analysis being superior in 35 instead of 31 cases for the yen during the support period. The resulting impression of negligible risk considerations demonstrates that the surplus yields of technical analysis do not result from increased volatility, which agrees roughly with prior work as summarized in Section I.

Up to this point, the impression of persistent profitability is strongly confirmed, thus challenging the idea of rational actors in foreign exchange markets. In order to see *ex ante* and *ex post* optimality in more detail, Tables 3-5 show various reference numbers of the calculations, separated for the three currencies. In each case the two best and worst oscillators in the support period and for the whole period are presented (8 cases) and, correspondingly, the best and worst momentum variants, using the Sharpe ratio as a yardstick (4 cases).

Taking the US dollar (Table 3), for example, the 2/40-oscillator was the best variant of the 33 oscillators investigated in the support period. Following this rule would have earned profits of 1.99 DM compared to 1.09 DM for simply investing the money in US dollars. Comparing the profits to the second-best rule shows that the risk adjustment via the Sharpe ratio leads to somewhat different results than simple profit calculations. The relative advantage changes when turning to the right half of the table, giving figures for the out-of-sample period. The 2/40-oscillator now ranks only 30th (out of 33 oscillators), although it still beats buy-&-hold. The values of the proposed T-test will be discussed later.

Under these circumstances, looking at the entire period may blur the picture. In the period 1/1981-12/1991 the 2/40-oscillator ranks in the middle. Now the first-ranking 5/25-oscillator looks superior (fifth row in Table 3), but what does this mean? The point of decision

TABLE 3

PROFITABILITY OF TECHNICAL ANALYSIS RULES: DM/US$

Instrument	1/1981 - 12/1985									1/1986 - 12/1991								
	Rank-ing	Sharpe ratio	Net profit in DM	Number signals	Profit Sum in DM	Profit Number	Loss Sum in DM	Loss Number	T-test	Rank-ing	Sharpe ratio	Net profit in DM	Number signals	Profit Sum in DM	Profit Number	Loss Sum in DM	Loss Number	T-test
O 2/40	1	0.425	1.99	49	2.93	22	0.94	27	0.982	30	0.104	0.53	83	1.86	19	1.33	64	1.457
O 4/8	2	0.409	2.24	151	4.40	73	2.16	78	1.125	31	0.064	0.33	193	2.77	75	2.44	118	1.247
O 10/20	32	0.146	0.85	64	2.68	28	1.83	36	-0.212	3	0.315	1.40	73	2.37	38	0.97	35	2.766*
O 10/50	33	0.105	0.67	25	1.71	14	1.04	11	-0.411	24	0.135	0.70	35	1.67	14	0.97	21	1.689*
O 5/25	9	0.323	1.59	54	2.82	26	1.23	28	0.535	4	0.307	1.41	65	2.23	29	0.82	36	2.628*
O 5/30	3	0.367	1.74	50	2.79	23	1.05	27	0.712	8	0.253	1.17	61	2.08	29	0.91	32	2.317*
O 10/50	33	0.105	0.67	25	1.71	14	1.04	11	-0.411	24	0.135	0.70	35	1.67	14	0.97	21	1.689*
O 6/10	26	0.216	1.40	124	3.82	49	2.42	75	0.272	33	-0.037	-0.18	159	2.30	52	2.48	107	0.713
M 25	1	0.471	2.05	79	3.00	35	0.95	44	1.063	6	0.132	0.66	111	1.99	39	1.33	72	1.578
M 40	10	0.165	0.85	65	2.15	26	1.30	39	-0.268	5	0.135	0.68	105	1.88	31	1.20	74	1.557
M 25	1	0.471	2.05	79	3.00	35	0.95	44	1.063	6	0.132	0.66	111	1.99	39	1.33	72	1.578
M 30	8	0.178	0.95	83	2.24	32	1.29	51	-0.154	9	0.077	0.39	105	1.92	32	1.53	73	1.386
Buy&Hold	-	0.201	1.09	-	-	-	-	-	-	-	-0.160	-0.81	-	-	-	-	-	-

* Significant at a 95% level.

TABLE 4

PROFITABILITY OF TECHNICAL ANALYSIS RULES: DM/YEN

Instrument	1/1981 - 12/1985									1/1986 - 12/1991								
	Rank-ing	Sharpe ratio	Net profit in DM	Number signals	Profit Sum in DM	Profit Number	Loss Sum in DM	Loss Number	T-test	Rank-ing	Sharpe ratio	Net profit in DM	Number signals	Profit Sum in DM	Profit Number	Loss Sum in DM	Loss Number	T-test
O 5/30	1	0.320	0.45	49	0.74	21	0.29	28	0.772	25	0.186	0.43	63	1.00	28	0.57	35	1.234
O 6/30	2	0.317	0.44	43	0.71	20	0.27	23	0.747	21	0.213	0.50	57	1.04	26	0.54	31	1.377
O 8/50	32	0.081	0.12	31	0.43	13	0.31	18	-0.257	3	0.279	0.64	31	1.00	14	0.36	17	1.805*
O 8/40	33	0.060	0.10	35	0.46	15	0.36	20	-0.299	14	0.228	0.54	35	0.97	18	0.43	17	1.521
O 2/25	3	0.291	0.46	71	0.84	29	0.38	42	0.715	2	0.280	0.60	95	1.18	33	0.58	62	1.743*
O 6/30	2	0.317	0.44	43	0.71	20	0.27	23	0.747	21	0.213	0.50	57	1.04	26	0.54	31	1.377
O 4/8	31	0.090	0.16	157	1.07	61	0.91	96	-0.154	32	0.107	0.21	191	1.45	67	1.24	124	0.772
O 6/10	22	0.134	0.26	131	1.01	52	0.75	79	0.121	33	0.007	0.01	155	1.22	64	1.21	91	0.242
M 25	1	0.311	0.44	69	0.73	32	0.29	37	0.793	7	0.230	0.52	89	1.17	32	0.65	57	1.515
M 35	10	0.044	0.06	67	0.49	23	0.43	44	-0.479	3	0.265	0.59	69	1.12	24	0.53	45	1.692*
M 5	2	0.253	0.43	221	1.29	79	0.86	142	0.720	2	0.269	0.52	268	1.72	102	1.20	166	1.669*
M 35	10	0.044	0.06	67	0.49	23	0.43	44	-0.479	3	0.265	0.59	69	1.12	24	0.53	45	1.692*
Buy&Hold	-	0.116	0.21	-	-	-	-	-	-	-	-0.031	-0.07	-	-	-	-	-	-

* Significant at a 95% level.

TABLE 5

PROFITABILITY OF TECHNICAL ANALYSIS RULES: DM/POUND

Instrument	1/1981 - 12/1985									1/1986 - 12/1991								
	Rank-ing	Sharpe ratio	Net profit in DM	Number signals	Profit Sum in DM	Profit Number	Loss Sum in DM	Loss Number	T-test	Rank-ing	Sharpe ratio	Net profit in DM	Number signals	Profit Sum in DM	Profit Number	Loss Sum in DM	Loss Number	T-test
O 8/20	1	0.303	1.76	66	2.93	33	1.16	33	1.795*	2	0.154	0.72	85	2.15	34	1.43	51	0.524
O 2/25	2	0.298	1.89	93	3.37	33	1.48	60	1.615	31	0.022	0.11	121	1.98	31	1.87	90	-0.186
O 2/10	32	0.149	1.09	167	3.95	60	2.86	107	0.963	30	0.039	0.15	205	2.52	62	2.37	143	-0.180
O 6/10	33	0.124	0.84	137	3.52	53	2.68	84	0.871	32	0.005	0.02	183	2.43	59	2.41	124	-0.325
O 8/20	1	0.303	1.76	66	2.93	33	1.16	33	1.795*	2	0.154	0.72	85	2.15	34	1.43	51	0.524
O 10/20	6	0.278	1.61	66	2.87	32	1.26	34	1.643	4	0.145	0.66	85	2.00	33	1.34	52	0.439
O 2/10	32	0.149	1.09	167	3.95	60	2.86	107	0.963	30	0.039	0.15	205	2.52	62	2.37	143	-0.180
O 6/10	10	0.124	0.84	137	3.52	53	2.68	84	0.871	32	0.005	0.02	183	2.43	59	2.41	124	-0.325
M 15	1	0.349	2.22	128	3.81	50	1.59	78	1.953*	2	0.138	0.67	161	2.45	53	1.78	108	0.401
M 5	10	0.075	0.57	263	4.26	91	3.69	172	0.597	9	-0.019	-0.07	309	2.84	98	2.91	211	-0.442
M 15	1	0.349	2.22	128	3.81	50	1.59	78	1.953*	2	0.138	0.67	161	2.45	53	1.78	108	0.401
M 5	10	0.075	0.57	263	4.26	91	3.69	172	0.597	9	-0.019	-0.07	309	2.84	98	2.91	211	-0.442
Buy&Hold	-	-0.039	-0.30	-	-	-	-	-	-	-	0.057	0.29	-	-	-	-	-	-

* Significant at a 95% level.

was at the end of 1985 when a "rational" investor probably would have chosen the 2/40-oscillator, because it was superior to the 5/25-oscillator. With hindsight, the 4/20-oscillator would have been the optimal choice for the out-of-sample period (not printed in Table 3) but this one ranked 24th in the support period. Who would be courageous enough to employ either the 4/20- or the 5/25-oscillator at the end of 1991, i.e. the best oscillators over the last six or 11 years?

For all currencies, this kind of instability is immediately recognizable as far as the respective best rules are concerned. Only a few of the documented variants in the support period, which are particularly profitable, are also with the winners in the out-of-sample period, namely, the 8/20-oscillator for the pound and the 2/25-oscillator for the yen, respectively declining from rank 1 to 2 and climbing from rank 3 to 2. Furthermore, the 15-momentum for the pound falls from first to second position. This kind of relationship is certainly not systematic, even for the pound.

This is shown by two additional calculations comparing the ranks of technical rules for the support and the out-of-sample period (see Table 6). Firstly, all 6 Spearman coefficients of rank correlation, separated for the oscillator and momentum rules as well as for three

TABLE 6

RANKING OF TECHNICAL ANALYSIS RULES: 1981-1985 VS. 1986-1991

Spearman coefficient of rank correlation			
	US$	Yen	Pound
33 Oscillators	−0.129	−0.189	0.189
(T-statistics)	(−0.743)	(−1.083)	(1.087)
10 Momentums	0.430	−0.418	0.333
(T-statistics)	(1.290)	(−1.254)	(1.0)

On average ranking of the 50% best rules from 1981-85					
	US$	Yen	Pound	Av. realized	Av. expected*
16 Oscillators	17.5	18.1	15.6	17.1	16.5
5 Momentums	3.2	6.8	5.2	5.1	5.5

* No correlation.

currencies, are insignificant at the 95% confidence level. To complete this impression of instability, three out of the six correlations have a positive and three have a negative sign. Secondly, the initially better 50% of the variants in all three currencies, i.e. 63 rules, ranked only average in the following period. At least for the cases examined here, the relative profitability of the rules in the support period therefore provides no systematic statement concerning their relative profitability in the out-of-sample period. The unstable ranking orders in Sweeney (1986) and Leoni (1989) support this result.

The impression of persistent profitability also deteriorates dramatically when risk is considered in a way to catch the short-term perspective of professional participants. At first, the proposed Gauß-test is used, which stresses deviations from the buy-&-hold benchmark. The technical rules are then superior only in a minority of cases (see Table 2, in column 4). In the support period there are two technical analysis rules for all three exchange rates (129 cases) significantly better than buy-&-hold (i.e. a share of 2%). The share increases to 28% in the out-of-sample period. Over the whole period, it falls to 19%. This shows some limitation to the measured significance of the short-term superiority of technical analysis profits compared to buy-&-hold. One could argue, however, that there are at least profitable opportunities for the use of technical analysis: the question is whether they can be identified and exploited.[8] Relying on the results from a support period, no single technical analysis rule in our sample that was significantly superior in the support period was also so in the out-of-sample period.

There are further calculations demonstrating the inherent risk for professional speculators. For this purpose, risk may be understood as coming into a substantial, although possibly temporary, loss situation. In this way, risk is measured as absolute losses, different from the Gauß-test highlighting relative loss positions. Such absolute losses, although probably only temporary, may deter even rational speculators who are aware of the chances of surplus yields from the use of technical analysis. This occurs because they do not possess either the personal or the institutional conditions needed to hold out during the unavoidable phases of loss. The use of the technical

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[8] It is common practice for professionals to shift their technical analysis rule whenever this seems advantageous. We did not test, whether more frequent shifts would have improved the risk-adjusted profitability. Furthermore, there remains the possibility of unknown ways to identify *ex ante* advantageous rules.

analysis described is only successful when it is followed consistently over years, which is made quite difficult by various factors.

Firstly, as a rule, the majority of signals are false. Looking at the results presented in Tables 3-5, in only 4 of the 72 cases did a technical analysis rule come out with more profit than loss signals (see also Schulmeister 1987, p. 20).

Secondly, there are periods in which adhering to technical analysis leads to losses over a long duration, which is not easy to bear for decision-makers. Table 7 shows such loss situations for the 9 best technical analysis rules based on complete years in annual percentages. Take, for example, the US dollar and imagine imitating the situation of a real decision-maker. Assuming this person applied the best oscillator of the support period, the 2/40, from 1986 on, he might feel happy in the first two years but could lose his job in 1988 because of the underperformance of 16 percentage points. Assuming you want to be even more conservative and decide to follow the best oscillator out of the whole period, the 5/25, from 1992 onwards, can you feel comfortable? Maybe not, when you look at its performance during the years 1982-84.

Thirdly, many consecutive false signals also put a strain on the power of endurance throughout the year. Thus even the best technical analysis rule for the US dollar over the whole period, which nobody knew *ex ante*, the 5/25-oscillator, exhibited in the entire period 3 phases with 5 continuous false signals, which lasted 13 weeks with a 0.15 DM loss, 16 weeks with a 0.08 DM loss and 4 weeks with a loss of 0.10 DM respectively. For the best DM/US$ rule in the support period, the 2/40-oscillator, once there were even 10 consecutive bad signals (14 weeks/0.17 DM loss) and twice there were 7 bad signals (5 weeks/0.19 DM loss; 4 weeks/0.09 DM loss). Somebody might still follow a technical rule after 2 or 3 continuous loss signals but what happens after that? Will the decision-maker switch to a more promising rule?

In summary, the currencies considered developed patterns which would have been exploitable for professionals with low transaction costs and regarding interest-rate differentials. From the restricted perspective of simple profit calculations as well as comparing the outcome with a buy-&-hold strategy, i.e. for risk-neutral investors, the evidence is overwhelming. This assessment still holds, when risk would be appropriately caught by the Sharpe ratio. Both results conform to previous studies.

TABLE 7

YEAR-BY-YEAR PROFITABILITY OF THE BEST TECHNICAL ANALYSIS RULES (IN %)*

Currency	Instrument	Ranking	Period	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Average** 1/81-12/85	Average** 1/86-12/91	Average** 1/81-12/91
US$	O 2/40	1	1/81-12/85	24.1	11.5	13.1	19.0	13.3	0.0	9.8	0.6	16.9	-2.4	5.4	16.2	5.1	10.1
	O 5/25	1	1/81-12/91	26.7	4.9	3.4	15.0	14.6	5.3	15.5	17.7	25.8	3.5	12.7	12.9	13.4	13.2
	M 25	1	both	25.2	8.4	9.7	18.6	20.0	0.4	13.4	5.7	19.7	-3.5	0.7	16.4	6.1	10.8
	Buy&Hold			23.1	9.7	19.8	20.5	-19.4	-19.5	-16.0	16.5	-2.2	-12.4	-2.0	10.7	-5.9	1.6
Yen	O 5/30	1	1/81-12/85	10.4	9.7	11.8	8.5	2.4	1.6	10.7	-0.8	14.1	12.7	-5.4	8.6	5.5	6.9
	O 2/25	1	1/81-12/91	15.6	9.7	5.9	11.9	1.6	4.1	11.5	1.5	14.1	12.7	2.7	8.9	7.8	8.3
	M 25	1	1/81-12/85	10.4	8.7	15.7	4.2	2.4	9.0	12.4	3.1	12.7	3.4	0.9	8.3	6.9	7.5
	M 5	1	1/81-12/91	12.5	9.7	0.0	11.9	5.6	13.9	3.3	7.7	4.2	8.5	4.5	7.9	7.0	7.4
	Buy&Hold			3.1	-3.9	16.7	5.9	-1.6	-0.8	7.4	9.2	-19.0	-7.6	8.2	4.0	-0.4	1.6
Pound	O 8/20	1	both	12.1	7.9	8.8	-0.3	14.2	5.9	2.4	1.7	11.2	-0.4	1.7	8.5	3.8	5.9
	M 15	1	both	21.1	6.5	11.1	0.8	13.7	6.5	-1.7	6.1	11.2	-1.5	-0.3	10.6	3.4	6.7
	Buy&Hold			-5.0	-7.2	7.0	-4.1	3.6	-14.1	9.1	14.5	-9.0	12.9	1.4	-1.1	2.5	0.8

* Based on the exchange rate of the beginning of the year.
** Average annual percentage return.

There are two major limitations to this perspective. First, the *ex post* view may lead to an unrealistic assessment of the relevant *ex ante* situation. Over time and in cross comparison of the currencies, no stable patterns seem to exist. On the contrary, the behavior of exchange rates in both dimensions appears to be distinct. Accordingly, technical analysis makes a profitable investment strategy possible almost independently from the specific rule. But the expected level of profits is below that of the best rules, because they cannot be identified by the suggested method. Furthermore, the profits were only calculated for periods of several years.

The second major limitation results from the question of the most appropriate inclusion of risk. The advantage deteriorates heavily when profit or Sharpe ratio calculations are replaced by the suggested form of Gauß-test. This weighs down the surplus yield from speculating with technical analysis rules against the deviations, compared to the performance of a buy-&-hold strategy at every subperiod, here assumed to be one month. Under this limitation, only a minority of technical analysis rules is significantly superior and none fulfils this condition for the support as well as for the out-of-sample period. Calculations of continuing, although temporary, loss positions further demonstrate the risk for speculators under the institutional condition of short-term performance measurement.

IV. Discussion of the empirical results

The empirical results do not allow for a clear-cut solution to our puzzle of reconciling persistent profitability with rational behavior, but they influence the plausibility of some arguments for or against the efficient market hypothesis. This will be shown by discussing three major positions, firstly following the efficient market hypothesis, secondly emphasizing forms of irrational behavior as relevant for the market outcome and thirdly stressing institutional factors determining behavior.

(1) Maintaining the hypothesis of purely efficient markets, traditional arguments stress, the empirical results could be accidental or could be explained by unknown time-variable risk premia. Both pos-

itions are weakened by persistent use and persistent profitability of technical analysis independently of various measurements of risk. Therefore, the main remaining argument in defense of efficient markets may be – assuming that interventions matter at all (see Dominguez and Frankel 1993) – the destabilizing influence of central bank interventions in otherwise efficient markets (e.g. Sweeney 1986, Levich and Thomas 1993). This proposition, however, is neither empirically proved nor, with respect to the amount and continuity of technical analysis excess returns, intuitively compelling. On the contrary, there is some empirical evidence supporting the notion of profitable stabilizing central bank interventions (outside the EMS, e.g. Leahy 1989, Goodhart and Hesse 1993).

(2) A second interpretation could state irrational behavior which is not compensated by rational actors as in (1) but which has relevance for the market outcome (see e.g. Boothe and Longworth 1986 or Tronzano 1992). Whereas this irrationality was traditionally identified with participants who cause exploitable patterns (e.g. Schulmeister 1987), with the notion of persistent profitability the focus may shift from not using technical analysis at all to not using it intensively enough. The problem with this position is therefore obvious. Although there may be many reasons for noise in the market and even convincing arguments for noise influencing financial market prices (see Shleifer and Summers 1990 for an introduction), there is no explanation why rational actors should not detect the sources of noise which persist over years and can be exploited profitably.

Summing up, the measured persistent profitability of technical analysis on foreign exchange markets cannot be explained in a convincing manner by the above approaches. "Pure efficiency" neglects the widespread use of technical analysis by professionals, whereas "inefficiency" underestimates the power of market forces in the highly competitive foreign exchange markets.

(3) A possible answer to our puzzle may rely on institutional settings determining the behavior of professional speculators. Thus, market participants use technical analysis because they are attracted by promising surplus yields (the Sharpe ratio perspective) but personal and institutional risk restrictions limit the ability fully to exploit the theoretical profit potential (the Gauß-test perspective).

In more detail, the Sharpe ratio as well as the approach chosen by Sweeney (1986, also calculated by Levich and Thomas 1993) give a reasonable long-term measurement for risk-adjusted profits: in this case, technical analysis is profitable and its use rational. The explanatory problems of fundamental analysis (see MacDonald and Taylor 1992 or Frankel and Rose 1994) provide a further incentive for applying technical analysis. But why do market participants not make more use of profitable technical analysis rules and thus make them ultimately unprofitable? A reason lies – as our analysis suggests – in the risk for speculators who are evaluated on a short-term basis. This control mechanism gives an incentive to interrupt or abolish the use of technical analysis because of temporary situations with less favorable outcomes.

We propose the existence of a trade-off from applying technical analysis between long-term profitability and short-term risk limits for professional users under the given institutional circumstances. Most users of technical analysis may choose a mixed position, reflecting their simultaneously profit-seeking and risk-averse behavior. Such gradual behavior could, in principle, explain why technical analysis is persistently applied by rational speculators without eliminating persistent profitability, according to standard risk adjustments. It is also consistent with some ambiguity in evaluating the efficient market hypothesis for foreign exchange markets (Levich 1989, Tronzano 1992, Frankel and Rose 1994).

We do not claim, however, to have solved the puzzle, only to have undertaken exploratory exercises in shaping a new hypothesis, with some limitations. The results gained so far can be only tentative because of the various reasons of a missing T-test significance. There is a lack of strict formulation which has not been addressed in this paper. An approach deducting inefficient outcome from rational behavior under asymmetric information may show a fruitful direction (see e.g. Froot, Scharfstein and Stein 1992). Furthermore, the puzzle has been shifted to another level of analysis, posing the question of whether the prevailing institutional control mechanisms can be regarded as efficient. Extending the investigation by analyzing institutional efficiency may lead to the proposition that persistent profitability is caused by a lack of stabilizing speculation. As a last caveat, the evidence for the suggested hypothesis is based on only one set of data and on very simple technical analysis rules, chosen to consider the persistence issue, but which may be misleading in an

unknown way, because there now exist much more sophisticated forms of technical analysis (see Ridley 1993; an example is given by Pictet *et al.* 1992).

V. Conclusions

Building upon published studies, our calculations examined persistent profitability of technical analysis rules for three exchange rates with more recent data, a larger number of variants and under rigorous methodological conditions. In more than 80% of all the cases investigated, risk-adjusted profitability was confirmed applying the Sharpe ratio and also taking account of swap and transaction costs. The ranking order between various variants, however, is extremely unstable, limiting the realization of surplus yields. A different risk consideration via the Gauß-test, probably better reflecting the situation of the dominant professional speculators, indicates no significant time-consistent advantages for technical analysis compared to a buy-&-hold strategy.

Thus, the result is not as favorable for using technical analysis compared to Dooley and Shafer (1983), Sweeney (1986), Schulmeister (1987 and 1988), Levich and Thomas (1993) or almost all the other recent studies cited. In our interpretation, the differentiating factor could be a usually incomplete understanding of the risk that the decision-makers face. Our hypothesis in explaining the puzzle of persistent profitability emphazises that existing shorter-term oriented control mechanisms hold off from fully exploiting the chances of technical trading. The exploratory investigations presented provide some evidence in support of the hypothesis.

Summing up, persistent profitability of technical analysis does not necessarily contradict the hypothesis of efficient learning on currency markets. Rather, under the current institutional circumstances, it may be rational to leave these profit opportunities partly unused.

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