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The Distribution of Foreign Exchange Price Changes: Trading Day Effects and Risk Measurement

JAMES W. McFARLAND, R. RICHARDSON PETTIT, and SAM K. SUNG*

ABSTRACT

This study investigates the nature of price changes in a variety of major and minor foreign exchange markets. The results suggest that the log of price changes over one (trading) day intervals seems to follow a non-normal stable distribution function. Different measures of location (and to lesser extent scale) are present for different days of the week. Dollar denominated price changes are high on Mondays and Wednesdays and low on Thursdays and Fridays for all currencies. The Wednesday-Thursday result is consistent with the settlement procedures used in foreign exchange transactions in the dollar. The Friday-Monday result is consistent with an increase in demand for the dollar prior to the weekend.

THIS STUDY OFFERS SOME previously unavailable results on the nature of price changes in a certain set of speculative markets. In particular, this is a study of the distributional characteristics of daily and weekly price changes for a number of major and minor foreign exchange markets. The results document the existence of non-normal stable distributions for price changes in foreign exchange markets. These price change distributions differ by day of the week in ways that are only partly attributable to the institutional structure of the market. The results of the study are interpreted within the context of understanding how foreign exchange markets operate, and within the context of prior studies of stock market data concerned with summarizing the probability distribution of price changes for different intervals, including days of the week.

Since Bachelier's [1] original treatise that contained the proposition that speculative market prices follow a process that could be described by a normal distribution, there have been numerous alternative attempts to describe the stochastic processes which characterize speculative market prices. These studies have not resulted in any generalized description of the probability distribution of price changes in such markets. Indeed, the evidence suggests substantial differences in the process among various types of financial instruments. The failure to achieve consensus can be traced to the lack of robustness in the statistical procedures employed to estimate processes and to differences in the underlying institutional or economic arrangements which are unique to that market. The possibility of differences in the information set used to assess value or differences in technology for transmitting information makes it important to secure additional

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knowledge of the pricing process in different speculative markets. Such knowledge is essential to the formation of estimates of risk and return for the construction of optimal investor portfolios, as well as for understanding how speculative markets operate.

The implications of the results of this investigation for the nature of speculative markets are both general and specific. General implications are reached concerning the process by which foreign exchange markets adjust to either information flows or institutional arrangements on a daily basis, and some fairly strong conclusions regarding the use of daily data in financial research are obtained. The study complements the growing body of literature that has been concerned with day effects and nontrading interval effects on stock market returns (French [14], Gibbons and Hess [15], and Oldfield and Rogalski [26]) by employing day of the week "treatments" of the underlying price generating process. Evidence is offered on the nonstationarity of the distributions across days of the week; and thus, on whether speculative market price changes are independently and identically distributed.

Specific conclusions are reached on the distributional characteristics of spot and forward foreign exchange price changes. Evidence is presented on the degree to which the data may be summarized by a particular distribution, and whether the distributions differ among currencies, days, time intervals, or spot and forward markets. In particular, the analysis concentrates on assessing whether the empirical distributions best fit normal, non-normal stable Paretian, or more complex compound or subordinated processes. The importance of this for practitioners concerned with estimating foreign exchange risk is paramount.

I. The Theory

A. *Distributional Properties of Speculative Price Changes*

In competitive financial markets, the prices which exist at a point in time reflect the interaction of a large number of suppliers and demanders, each of whom is reacting to a set of information that is pertinent to the assessment of returns and risks. Price changes that are measured over a period of time reflect the "collective" effect of these actions. Whatever the shape of the frequency distribution of price changes created from a single bit of information being sent to the market, the process by which price changes are formed over some chronological period should follow a generalized central limit theorem. This generalized central limit theorem [17] states that the sum of independent drawings from any probability distribution (or the price changes themselves) tends to a stable (Pareto-Levy) distribution as the number of items in the sum gets large. When the drawings are from a distribution with a finite mean and variance, the limiting distribution is normal. The non-normal stable distribution, of course, has a larger proportion of the distribution in the tails and at the center than the normal. A compound process is a combination of normal or stable distributions that contains location, scale, or characteristic exponent parameters which are different for different subpopulations. For example, for different subgroups of observations subject to different generating processes (occurring, say, in response to different kinds of informational events), the collection of price changes observed is a compound process. These complex combinations may appear to have the general appearance of a non-normal stable distribution (see Mandelbrot and Taylor [25]), but certain statistical tests can be employed to discriminate between stable and compound processes as representing the structure of speculative market price changes.

These theories spawned a number of empirical studies which have attempted to determine which stochastic process seems more representative of speculative markets in general. Unfortunately, few of these studies have developed from an analysis of the information flows which drive the demands for financial market instruments. As a consequence, many of these studies are ad hoc, and most simply address the question of whether price changes are best described by normal, non-normal stable, or compound processes. However, one exception is a recent article by Oldfield and Rogalski [26] that develops and tests a compound process for the generation of stock market information over trading and nontrading periods. While they do not specify explicitly the distribution that results from this process, they point out that means and variances of price changes do differ depending on the interval considered; and thus, they provide insights directly into the process by which the market prices of financial assets are generated. A similar approach is followed in this paper in an analysis of daily foreign exchange prices.

B. Information Flows and Foreign Exchange Markets

The rate of information flow that makes an impact on foreign exchange prices varies with the time of the day and the day of the week. Moreover, the apparent influence of governments on the information set in these markets is likely to create a patterned flow. In fact, much of the relevant information that is released by governments is made available to the public in recurring patterns. The weekend, for example, is often a more active period for information flows for foreign exchange markets than for most other financial assets. It is possible that the distribution of price changes on Monday, reflecting the events of the weekend, is different from price changes for other days of the week. The distribution may also be different because of the length of the nontrading interval between Friday and Monday. Moreover, Thursdays may differ if that is the day on which regular announcements are made, e.g., central bank publication of money supply figures.

In addition, the clearing system for foreign exchange transactions involving the dollar gives rise to an opportunity loss of interest for Wednesday transactions. Transactions on Wednesday clear for "good" value on Friday in the foreign currency, but not until Monday for the U.S. dollar. The loss of two days' dollar interest results in a lower demand for (or higher supply of) dollars relative to other currencies so that the value of other currencies relative to the dollar will be higher on Wednesday. Consequently, the Tuesday to Wednesday price change will tend to be positive, and the Wednesday to Thursday price change will tend to be negative.[1] Levi [22] previously observed a similar effect involving the Canadian/U.S. exchange rate.

[1] There have been at least three other day of the week studies—all using stock market data. Cross [6] observed nonrandom movements in the Standard and Poor's Composite Stock Index. Particularly evident was a relation between Friday returns and Monday returns. In addition, Gibbons and Hess [15] have reported finding a significant negative return on individual common stocks on Monday. Their sample consisted of the 30 securities that make up the Dow Jones Industrial Average. French

C. The Model

A process that provides for differences by day of the week that may be strong in foreign exchange markets is modeled by

$$\ln(P_{\tau+\delta}/P_\tau) = e_{\tau+\delta} + d_m B_m + d_t B_t + d_w B_w + d_{th} B_{th} + d_f B_f$$

In this expression δ is the time interval between the end of one trading period and the end of the next trading period, and $P_{\tau+\delta}/P_\tau$ is the price ratio. The random variable of interest is the natural logarithm of the price relative, $\ln(P_{\tau+\delta}/P_\tau)$. The logarithm of price ratios must be used for analyses of foreign exchange markets because the prices themselves reflect a ratio of the market's assessment of the value of one currency relative to another. The first term, $e_{\tau+\delta}$, represents the underlying generating process for the market. The remaining five terms represent effects attributable to the day of the week on which the price change occurs. The d_k terms are dummy values while the B_k terms are used to represent the additive process describing the distribution relevant to that day. Thus, B_m indicates the process beginning at Friday's close and continuing through to Monday's close. The subscripts *m*, *t*, *w*, *th*, and *f* refer to each day of the week. The processes $e_{\tau+\delta}$ and B_k are purposely not completely specified.[2] Indeed, this study attempts to supply a partial description of this process through parameter estimates of the distributional characteristics of B_k and $e_{\tau+\delta}$. The B_k and $e_{\tau+\delta}$ would follow some distributional form according to our hypothesis. In fact, given the frequency and size of transactions in most major foreign exchange markets, there is reason to hypothesize that each daily distribution can be described by a single limiting process. Whatever the underlying distribution of individual transaction price changes, it seems reasonable, based on the generalized central limit theorem, to hypothesize that a limiting (normal or non-normal stable) distribution has been achieved within a 24 hour period. If this is not true, of course, it should appear in our inability to summarize daily price changes by a unique distribution.[3]

If the factors, B_k's are distributed normally with different means or variances, then the sequence of daily price changes would be a compound normal process and would have a larger proportion of the probability in the tails than a normal distribution with the mean and variance equal to those computed from the sequence of daily returns. If the factors are distributed according to a stable Paretian process, the daily price changes will be distributed according to a compound stable process. In either case sequential daily changes could not be

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[14] also found significant negative returns on Mondays in a 20 year analysis of Standard and Poor's Index.

[2] It could be represented as, say, a continuous diffusion process of the Wiener type. But since each period contains both a nontrading interval and a trading interval, and the process for each may differ, there seems to be no reason to constrain it to a particular model. The random walk and fair game models would be special cases of this formulation. Most other studies of speculative price behavior also focus on an attempt to specify more completely this process for different financial markets. Studies of the fair game or martingale properties of a price series, for example, Giddy and Dufey [16], would concentrate on analyzing the relationship between $e_{\tau+\delta}$ and $e_{\tau+\delta+\eta}$.

[3] Oldfield and Rogalski [26] estimated parameters of only the normal distribution, but their results suggest that while price changes over individual transactions are not normally distributed (using the Studentized Range test), the trading day distributions are not as non-normal for each of the five securities they observed.

adequately characterized by a single distributional form. The stability under addition property of the non-normal stable distribution suggests that weekly price changes will be stable if the day of the week changes are stable; similarly, if the day of the week changes are normal, then the weekly price changes will be normal (see Blattberg and Gonedes [2]).

II. Prior Studies

Several probability models have been suggested as appropriate for describing price changes in speculative markets. Until the early 1960s the prevalent belief was that the normal distribution adequately described rate of return distributions for stocks. This conclusion was largely based on the work of Bachelier [1], the later work of Osborne [27], and Kendall [20] in which price movements were viewed as a Gaussian random walk.

Mandelbrot [24], however, noting that empirical distributions of price changes had extraordinarily long tails and were peaked relative to samples from normal populations, suggested the non-normal stable Paretian distribution as an alternative. Several studies have since shown that common stock price changes (Fama [9, 10] and Teichmoeller [31]) and changes in other speculative prices (U.S. Government Treasury Bills by Roll [29], commodity futures by Dusak [8], and foreign exchange markets by Westerfield [33, 34]) have properties conforming to those of stable probability distributions. Although the non-normal stable distribution has received considerable support as the model to use in describing price changes in speculative markets, there have been several studies in which alternative formulations have been proposed and different conclusions have been reached (see, e.g., Blattberg and Gonedes [2, 3], Westerfield [35], Hsu, Miller, and Wichern [18], and Upton and Shannon [32]). These studies have failed to arrive at a concensus regarding the type of distribution that characterizes price changes in these markets. For this reason it is appropriate to keep in mind that different financial markets may be characterized by different distributional forms.

Nevertheless, to adequately describe the underlying stochastic process for price changes, models that explicitly incorporate factors that may affect price changes may be required. This is the approach of Oldfield and Rogalski [26], who suggest that returns during each day were identically distributed, but that overnight and over-weekend distributions differed from those apparent during the day. Their results provided support for their contention that returns over an arbitrary interval included multiple jump processes.[4]

Far less attention to short run distributional characteristics has been given to analysis of the structure of foreign exchange rate changes. Two primary studies investigating the distributional properties of foreign currency markets are those by Westerfield [33, 34] and Rogalski and Vinso [28].[5] Westerfield found the

[4] Oldfield and Rogalski [26] propose a general stochastic process that is composed of a diffusion process and multiple jump processes. A continuous (Wiener) diffusion process is assumed to operate during trading and nontrading periods. Stochastic jump processes for overnights, holidays, weekends, and weekend-holidays are incorporated into the overall process of price changes. Thus, the unconditional density for the price change process incorporates densities for the diffusion and jump processes.

[5] There are, however, many studies of foreign exchange markets that are indirectly concerned with distributional issues through tests of market efficiency including, for example, Cornell and Dietrich [5], Giddy and Dufey [16], and Logue and Sweeney [23].

distributions of spot and forward exchange rates were more closely described by stable distributions with characteristic exponents of less than two than by normal distributions or mixtures of normals for both fixed and floating exchange rate periods. Rogalski and Vinso concluded that the Student's *t*-distribution provides a reasonable fit for floating exchange rate periods.

We now explore the several contentions suggested by the model formulated in Section I.

III. Hypotheses and Methodology

Our analysis centers on three different time series of daily foreign exchange rate changes: first, the sequential twenty-four hour changes of all daily rates from Monday to Tuesday, Tuesday to Wednesday, Wednesday to Thursday, Thursday to Friday, and the seventy-two hour changes from Friday to Monday; second, the series of changes by day of the week, i.e., all Friday to Monday changes, Monday to Tuesday changes, etc.; and, third, the series of weekly changes, i.e., Monday to Monday changes, Tuesday to Tuesday changes, etc. Alternative hypotheses for these time series are that foreign exchange rate changes follow a normal (Gaussian) process, foreign exchange rate changes follow a non-normal, symmetric stable Paretian process, and foreign exchange rate changes follow a compound normal or stable process. To test these hypotheses, the chi-square and Studentized Range tests are used to test for conformance with the normal distribution (see Kendall and Stuart [21], Shapiro, Wilk, and Chen [30], and Fama and Roll [11, 12]), and the chi-square test and two tests of invariance under addition are used to test for conformance with the stable distribution.[6]

To specifically investigate day of the week effects it is necessary to test for equality of the cumulative distribution functions for the five days of the week. The Kruskal-Wallis nonparametric tests for equality of location parameters and multiple comparisons and the Siegel-Tukey test of equality of scale parameters are used. The Kruskal-Wallis and Siegel-Tukey tests are also used to test the hypothesis that the cumulative distribution functions for the weekly changes are equal.[7]

[6] Stable distributions are invariant under addition, by definition. That is, any finite sum of independently and identically distributed stable variables with a given characteristic exponent is distributed as a stable random variable with the same characteristic exponent. This property of "stability" forms the basis for two tests of stable distributions. The two tests of stability used in this paper are explained in Fama and Roll [12] and Hsu, Miller, and Wichern [18] and are referred to as the chronological and random ordering methods for testing stability. The parameter estimation procedures for the stable distribution are taken from Fama and Roll [11, 12]. For estimators of the location parameter in the stable distribution, the results of Fama and Roll suggest the 0.25 truncated mean when the characteristic exponent is near 1.0, the 0.5 truncated mean when the characteristic exponent is 1.3 to 1.5, and the 0.75 truncated mean when the characteristic exponent is 1.7 to 1.9. Since nearly all estimates of the characteristic exponent in this study and Westerfield's [34] are less than 1.5 and greater than 1.1, the 0.5 truncated mean is used as the estimator of the location parameter. The estimator for the dispersion parameter is $\hat{c} = (\hat{x}_{.72} - \hat{x}_{.28})/2(.827)$, *where* $\hat{x}_f$ is the f sample fractile. The estimator of the characteristic exponent is obtained by first computing $\hat{z}_f = (\hat{x}_f - \hat{x}_{1-f})/2\hat{c}$. Tables of the stable distribution are then used to select an estimate of the characteristic exponent which makes $\hat{z}_f$ close to z_f.

[7] The Kruskal-Wallis and Siegel-Tukey procedures are discussed in Conover [4].

IV. Data

Eleven foreign currency markets are analyzed in this study. Spot markets are analyzed for the exchange of dollars for four major trading currencies: the British pound, the German mark, the Japanese yen, and the Swiss franc; and for three less actively traded currencies: the Australian dollar, the Spanish peseta, and the Swedish krona. Three month forward markets are also analyzed for the four major currencies. There are no active forward markets for the minor currencies.

For the major currencies the prices are dollar bids recorded at 1:00 P.M. on the New York Interbank Market. For the minor currencies the rates are the noon buying rates in the interbank market for cable transfers of foreign exchange, certified for customs purposes by the Federal Reserve Bank of New York.[8] Prices are on a daily basis from 2 January 1975 through 29 June 1979. This four and one-half year period is by far the longest continuous period investigated since the floating exchange rate system was adopted. (Westerfield [33, 34] analyzed weekly data for Thursdays covering the period January 1962 to July 1975.)

The description of the data used in the analysis is presented in Table I. The data are separated by day of the week and by weekly observation intervals. Differences in the two are fully accounted for by the absence of trading prices (usually due to holidays) on the immediate prior day. Thus, the large difference in Tuesday observations is due to the existence of a large number of Monday holidays. The day of the week observations from Tuesday through Friday are all 24 hour intervals. The Monday price changes are over a 72 hour interval.

The accuracy of the data was checked with a prior study to insure that the daily price data used were valid and representative.[9] Efforts were made to insure that all available observations were collected and correctly recorded. Price changes of more than one half percent were double checked for accuracy. Missing observations were checked to determine if the omitted data could be found. When the data were not available, the observation was treated as a holiday.

V. Empirical Results

The empirical results of the study are set forth in three sections which analyze: (1) consecutive daily price changes; (2) day of the week price changes; and (3) weekly price changes.

A. Daily Price Changes

Using all of the observed daily price changes, the sample moments of the normal distribution and stable distribution are presented in Table II. Also presented are the Studentized Range test for normality and the chi-square tests for the normal and stable distributions.

Interestingly, the parameter estimates that can be compared differ markedly. The location estimate for the stable differs from the estimate of the mean for the

[8] The major currency data were extracted from the *International Monetary Market Year Book* [19] and the minor currency data from *Selected Interest and Exchange Rates* [13].

[9] The comparison was made with weekly observations on the German mark collected by Wyatt [36] from the 2:00 p.m. New York interbank loan market.

Table I

Data Description: Sample Period and Number of Observations for Daily, Days of Week, and Weekly Data[a]

			Number of Observations										
	Sample Period		Daily	Days of Week					Weekly				
Currency	From	To		Mon.	Tues.	Wed.	Thurs.	Fri.	M-M	T-T	W-W	Th-Th	F-F
British pound	1/02/75	6/29/79	1100	205	199	222	221	210	204	224	228	223	217
German mark	1/02/75	6/29/79	1097	204	198	220	219	210	203	223	227	222	218
Japanese yen	1/02/75	6/29/79	1097	205	199	221	219	208	204	224	227	222	216
Swiss franc	1/06/75	6/29/79	1100	205	199	222	220	210	204	224	228	222	218
Australian dollar	1/06/75	6/29/79	1124	209	202	225	223	222	209	226	231	224	231
Spanish peseta	1/06/75	6/29/79	1124	208	201	225	223	222	208	226	231	224	231
Swedish krona	1/06/75	6/29/79	1125	208	202	225	223	222	209	226	231	224	231

[a] The sample period is from January 1975 to June 1979. The above description applies to both spot and three month forward rates for the British pound, the German mark, the Japanese yen, and the Swiss franc.

Table II

Sample Moments, Parameter Estimates of Stable Distributions, and Chi-Square and Studentized Range Statistics for Daily Exchange Rate Data

	Sample Moments				Test for Conformance with Normal		Stable		Test for Conformance with Stable	
Sample Currency	Mean[c]	Variance	Skewness	Kurtosis	Chi-Square[a]	Studentized Range[b]	Location[c]	Scale	Characteristic Exponent	Chi-Square[a]
British pound										
Spot	−.06486	.02505	−.900	16.681	345.59*	14.84*	.10531	1.61732	1.24	56.58*
Forward	−.05208	.02813	−.999	16.044	278.01*	14.30*	.15690	1.86893	1.29	38.03*
German mark										
Spot	.24428	.02632	−1.506	24.061	94.59*	15.88*	.20943	2.39023	1.40	8.12
Forward	.25043	.02765	−1.450	22.713	126.58*	15.45*	.20134	2.30537	1.36	14.71
Japanese yen										
Spot	.29303	.02620	−.093	13.325	529.39*	14.96*	.06054	1.52760	1.12	81.37*
Forward	.31176	.02968	−.194	13.221	406.43*	14.28*	.08160	1.64320	1.14	45.87*
Swiss franc										
Spot	.39390	.05312	−.426	15.525	268.26*	15.55*	.27772	2.56034	1.25	32.91*
Forward	.41401	.05639	−.476	15.708	296.30*	15.40*	.27464	2.54452	1.23	28.44*
Australian dollar										
Spot	−.14947	.03836	−26.602	831.809	103.70*	35.59*	.02844	1.05724	1.47	22.94*
Spanish peseta										
Spot	−.14587	.06108	−21.451	567.843	262.98*	31.19*	.06212	0.95495	1.22	35.52*
Swedish krona										
Spot	−.05518	.02378	−8.089	153.802	244.72*	24.06*	.09862	1.59822	1.34	53.39*

[a] Asterisk indicates significance at 1% level: critical value of 21.67 at the 1% level of significance and nine degrees of freedom.

[b] Asterisk indicates significance at the 1% level. Percentage points of the distribution of the Studentized Range statistic have been taken from David, Hartley, and Pearson [7].

[c] Figures are reported in U.S. dollars × 1000 for all currencies except the Japanese yen and the Spanish peseta. The yen and peseta are recorded in U.S. cents × 1000.

normal for the pound, the yen, and all the minor currencies. Moreover, the standard deviation of the normal distribution parameter estimates are between two and five times as large as the estimate of the scale parameter from the stable parameter estimates.[10] Kurtosis is high and the characteristic exponent for the stable estimates are typically well below 2.0. The most telling statistics are supplied by the chi-square and Studentized Range tests which suggest the distributions of daily price changes are highly non-normal for all currencies. Significantly, most of the chi-square statistics calculated for the estimates of the stable distribution also suggest that the distributions cannot be reasonably summarized as being from the Pareto-Levy class of stable distributions.

Table III presents results for the tests of stability under addition for both the chronological ordering method of Fama and Roll [12] and the random ordering method of Hsu, Miller, and Wichern [18]. These tests are designed to determine if the estimated characteristic exponent remains relatively constant as the number of price changes taken together increases. Hsu, Miller, and Wichern argue that if a series is generated from a stable Paretian distribution with no serial correlation and is homogeneous over time, then it must pass both tests of stability. If the estimates are not invariant under addition, then this is evidence to suggest that the daily data may follow a process that is more complex than can be described by a stable distribution.

The results display a tendency for the characteristic exponent to remain fairly constant for some currencies until sums of 15 or 20 are taken, and to rise for other currencies. In their simulation experiments, Fama and Roll observed a systematic downward bias in estimates of the characteristic exponent with smaller sample sizes. Thus, the estimates for the characteristic exponent should be adjusted upward. For the random ordering method the characteristic exponents remain fairly constant through sums of 15.

Collectively the Studentized Range, chi-square, and stability tests suggest that the distribution of daily price changes is too complex to be summarized neatly by either the normal or non-normal stable distribution. Since we have hypothesized that the possibility exists that days of the week may account for distributional differences, we turn our attention to an analysis of each day of the week.

B. Day of the Week Price Changes

The parameter estimates for the stable distribution for each day of the week are presented in Table IV. Since all holidays have been eliminated, these estimated parameters represent either 24 hour or 72 hour price change distributions. Table V contains chi-square values for these distributions, as well as for the normal distribution. The sample moments for the normal distribution are not presented to save space. The extreme non-normality of the daily price changes is established with the extraordinarily high chi-square values in the first section of Table V. These results offer a number of interesting conclusions. The distributions remain highly non-normal, but now only fourteen of the fifty-five chi-square values for the stable estimates are significant. Moreover, the parameter estimates

[10] The scale parameter is estimated from the 28th and 72nd sample fractile values. Thus the standard deviation would be expected to be only about fifty percent larger than the scale parameter if the distribution were truly normal.

Table III

Summary of Tests of Stability for Daily Data, Chronological Ordering Method, and Random Ordering Method

Chronological Ordering Method								
	Estimates for sums of:							
Sample Currency	1	3	5	7	10	15	20	25[b]
BP[a]								
Spot	1.24	1.30	1.42	1.26	1.53	1.51	2.00	2.00
Forward	1.29	1.30	1.45	1.38	1.72	1.54	2.00	2.00
GM								
Spot	1.40	1.30	1.20	1.22	1.34	1.25	1.66	2.00
Forward	1.36	1.41	1.19	1.20	1.28	1.19	1.68	2.00
JY								
Spot	1.12	1.19	1.19	1.23	1.33	1.33	1.25	2.00
Forward	1.14	1.21	1.24	1.20	1.36	1.33	1.33	2.00
SF								
Spot	1.25	1.33	1.42	1.26	1.25	1.66	1.62	2.00
Forward	1.23	1.29	1.39	1.24	1.23	1.60	1.58	2.00
AD								
Spot	1.47	1.41	1.45	1.33	1.75	1.54	1.63	2.00
SP								
Spot	1.22	1.32	1.23	1.32	1.15	1.25	1.23	1.18
SK								
Spot	1.34	1.48	1.30	1.24	1.25	1.34	1.29	1.17
Mean	1.28	1.32	1.32	1.26	1.38	1.41	1.57	1.85
Random Ordering Method								
BP								
Spot	1.24	1.27	1.24	1.22	1.47	1.40		
Forward	1.29	1.36	1.39	1.23	1.56	1.56		
GM								
Spot	1.40	1.36	1.38	1.48	1.37	1.20		
Forward	1.36	1.41	1.32	1.42	1.37	1.20		
JY								
Spot	1.12	1.15	1.07	1.20	1.26	1.21		
Forward	1.14	1.18	1.10	1.20	1.25	1.24		
SF								
Spot	1.25	1.39	1.27	1.30	1.43	1.33		
Forward	1.23	1.41	1.30	1.29	1.41	1.26		
AD								
Spot	1.47	1.49	1.65	1.53	1.40	1.79		
SP								
Spot	1.22	1.31	1.30	1.34	1.20	1.03		
SK								
Spot	1.34	1.26	1.24	1.29	1.27	1.16		
Mean	1.28	1.33	1.30	1.32	1.35	1.31		

[a] The British pound has 55 and 44 observations for sums of 20 and 25. The sample sizes are different only by plus or minus one for the rest of currencies.

[b] In some cases, actual values are greater than 2 and are shown here as equal to 2.0.

in Table IV suggest why the day of the week distributions conform more closely to the stable hypothesis than did the daily distributions. Specifically, there are large differences in the location parameter estimates and moderate differences in the scale parameter estimates among the days of the week. Mondays and

Table IV

Parameter Estimates for Stable Distribution for Days of Week Data

	Location[a]					Scale[a]					Characteristic Exponent				
Sample Currency	Mon.	Tues.	Wed.	Thurs.	Fri.	Mon.	Tues.	Wed.	Thurs.	Fri.	Mon.	Tues.	Wed.	Thurs.	Fri.
British pound															
Spot	6.546	1.117	6.433	−7.207	−1.624	17.573	14.137	15.080	18.980	12.937	1.19	1.19	1.20	1.29	1.19
Forward	6.802	3.594	2.818	−3.349	−1.415	19.998	17.297	19.305	20.545	14.057	1.28	1.26	1.33	1.37	1.19
German mark															
Spot	6.139	−.965	9.395	−1.844	−2.114	27.669	22.445	20.815	23.157	22.001	1.47	1.36	1.36	1.42	1.53
Forward	5.353	−.311	7.046	− .245	−1.615	28.880	21.872	23.160	22.614	20.239	1.52	1.32	1.38	1.38	1.49
Japanese yen															
Spot	5.979	1.316	.634	−1.715	−1.754	21.384	14.120	15.911	12.189	14.031	1.18	1.10	1.16	1.04	1.09
Forward	7.802	.166	−.389	−1.671	− .686	21.654	15.881	17.993	14.351	16.007	1.12	1.11	1.28	1.10	1.19
Swedish franc															
Spot	7.689	.328	8.653	−1.584	−1.630	24.379	23.261	27.903	28.926	20.583	1.11	1.23	1.37	1.37	1.12
Forward	7.281	2.133	6.521	.197	−2.443	25.919	24.473	28.356	29.735	21.043	1.13	1.22	1.35	1.41	1.19
Australian dollar															
Spot	.203	.430	1.917	1.080	−2.202	10.655	10.466	9.279	10.670	8.534	1.33	1.48	1.45	1.58	1.39
Spanish peseta															
Spot	1.384	2.931	3.078	−2.302	−1.736	9.591	8.765	8.046	7.820	9.722	1.24	1.24	1.09	1.24	1.31
Swedish krona															
Spot	4.366	.890	4.475	−1.483	−2.733	16.324	15.846	16.145	15.833	13.134	1.28	1.42	1.41	1.26	1.37

[a] Values are reported in dollars × 1000 for all currencies except the Japanese yen and the Spanish peseta. The yen and peseta are reported in U.S. cents × 1000.

Table V

Chi-Square Values for Tests of Normal and Stable for Days of the Week Data[a]

	Chi-Square Statistics for Normal					Chi-Square Statistics for Stable				
Currency	Mon.	Tues.	Wed.	Thurs.	Fri.	Mon.	Tues.	Wed.	Thurs.	Fri.
British pound										
Spot	104.90*	110.05*	74.62*	49.23*	117.81*	18.56+	34.92*	5.97	13.34	29.10*
Forward	91.68*	83.71*	29.62*	57.24*	101.62*	18.17+	23.81*	2.41	20.48*	23.33*
German mark										
Spot	40.17*	12.00	30.68*	30.22*	13.95	13.70	3.82	10.41	10.27	8.10
Forward	35.36*	19.93+	33.36*	50.50*	27.33*	13.79	6.09	9.68	17.21+	8.24
Japanese yen										
Spot	101.10*	69.74*	87.51*	128.49*	131.38*	25.39*	4.72	22.39*	16.30+	16.10+
Forward	82.61*	58.44*	78.50*	118.31*	122.77*	20.22*	12.36	23.62*	12.46	33.15*
Swedish franc										
Spot	96.80*	58.16*	45.16*	37.41*	71.71*	8.46	11.25	9.40	11.91	6.00
Forward	80.37*	43.61*	46.51*	43.77*	67.19*	6.95	6.23	8.45	22.05*	8.62
Australian dollar										
Spot	43.44*	25.57*	39.09*	19.51+	49.67*	16.12+	9.34	12.51	8.84	6.65
Spanish peseta										
Spot	49.40*	66.11*	93.44*	84.31*	32.38*	10.80	11.74	24.91*	14.58	3.36
Swedish krona										
Spot	88.37*	74.24*	53.00*	48.84*	48.36*	32.63*	41.76*	15.84+	15.48	12.95

[a] Asterisk indicates significance at 1% level and plus indicates significance at 5% level.

Wednesdays, for example, offer higher average price changes than Thursdays and Fridays for almost all currencies in both the spot and forward market. Kruskal-Wallis tests, presented in Table VI, show statistically significant differences between Mondays and Thursdays and Fridays and between Wednesdays and Thursdays and Fridays for almost all currencies in both the spot and forward markets.

The higher return on Wednesday and lower return on Thursday is consistent with the Wednesday effect that emanates from the settlement procedures existing in foreign exchange markets.[11] Our results seem to conform to those of Levi [22] in his study of the Canadian/U.S. exchange rate (though the settlement procedure is different for currency transactions involving the Canadian dollar).

It is not readily apparent why Monday would offer higher returns, nor is any explanation likely to be consistent with concepts of market equilibrium or rational market expectations. The price increase is more than would be offset by transactions costs. It is economically important, in most cases generating a return from a strategy of selling dollars on Friday and rebuying them on Monday well in excess of an extra 10 percent per year. This amount is substantially in excess of interest rate differentials that existed during the observation period.

The scale parameter for Monday is larger than for other days of the week in five of eleven currency markets. It is second largest in four, and third largest in two of the currency markets. This result is consistent with the hypothesis that seventy-two hour returns on Monday are slightly more disperse than are the twenty-four hour returns. Taken together, the location and scale differences offer strong evidence that the processes generating price changes differ among days of

[11] In fact, the price changes observed for Wednesday and Thursday can be used to infer the implicit interest rate used by the market to adjust for the two day interest loss on the dollar. If $E_w(\ln(P_{\tau+\delta}/P_\tau))$ and $E_{th}(\ln(P_{\tau+\delta}/P_\tau))$ represent the location parameter estimates for the log of price changes on Wednesday and Thursday, and $E(P_\tau)$ is the overall location estimate, then

$$r_w = \frac{E_w(\ln(P_{\tau+\delta}/P_\tau))}{E(P_\tau)} \frac{360}{2} \quad \text{and}$$

$$r_{th} = \frac{E_{th}(\ln(P_{\tau+\delta}/P_\tau))}{E(P_\tau)} \frac{360}{2}$$

constitute a measure of the magnitude of the market's adjustment in terms of an annual interest rate factor. For each of the eleven markets the implied rates are:

	Wednesday		Thursday	
	Spot	Forward	Spot	Forward
BP	4.8%	1.8%	7.3%	3.9%
GM	29.8	20.6	16.1	9.2
JY	5.6	−1.9	5.1	3.9
SF	25.2	16.2	18.6	10.8
AD	2.5		−2.1	
SP	3.0		3.5	
SK	27.1		19.2	

The figures, with two exceptions, imply positive interest rates. While the magnitudes vary considerably, the average value of 11% is only slightly in excess of the U.S. dollar interest rate observed over this period.

Table VI

Kruskal-Wallis Multiple and Pairwise Comparisons on Location for Days of the Week

A. Kruskal-Wallis Test of Location

Currency	Chi-square[a]	Currency	Chi-square*
British pound		Swiss franc	
Spot	142.03*	Spot	46.63*
Forward	56.50*	Forward	32.72*
German mark		Australian dollar	
Spot	62.45*	Spot	35.38*
Forward	35.84*		
		Spanish peseta	
Japanese yen		Spot	88.29*
Spot	38.44*		
Forward	41.56*	Swedish krona	55.30*
		Spot	

B. Kruskal-Wallis Multiple Comparisons

	Days									
Currency	Mon.				Tues.			Wed.		Thurs.
British pound										
Spot	T*	W	Th*	F*	W*	Th*	F	Th*	F*	F
Forward	T	W	Th*	F*	W	Th*	F*	Th*	F	F
German mark										
Spot	T	W	Th*	F*	W*	Th	F	Th*	F*	F
Forward	T	W	Th	F*	W*	Th	F	Th*	F*	F
Japanese yen										
Spot	T	W*	Th*	F*	W	Th	F	Th	F	F
Forward	T*	W*	Th*	F*	W	Th	F	Th	F	F
Swiss franc										
Spot	T*	W	Th*	F*	W*	Th	F	Th*	F*	F
Forward	T	W	Th*	F*	W	Th	F	Th	F*	F
Australian dollar										
Spot	T	W	Th	F	W	Th	F*	Th	F*	F*
Spanish peseta										
Spot	T	W	Th*	F*	W	Th*	F*	Th*	F*	F
Swiss krona										
Spot	T	W	Th*	F*	W	Th	F	Th*	F*	F

[a] An asterisk indicates the critical value at the 1% level of significance.

the week. Yet because the expected equilibrium returns from one currency value relative to another would be zero, the somewhat higher dispersion would not explain the high price changes from Friday to Monday. It is interesting to note that this result is the opposite of that suggested by Gibbons and Hess [15] and French [14], who found negative Monday returns in the U.S. stock market. The generally negative price changes for these currencies on Friday and positive price changes on Monday suggests a movement into the dollar before the weekend. Such a movement would be consistent with the dollar being the safest short term store of value during this study period. Importantly, there are few differences between spot and forward markets.

The estimate of the characteristic exponent varies little from one day of the week to another. Certainly, there is more variation between currencies than across days of the week, and there is no general tendency for Mondays to differ systematically from other days.

Additional tests for conformance with the stable hypothesis are given by the chronological ordering method to test for stability. These results are presented in Table VII. Estimates of the characteristic exponents on average rise slightly from individual observations to sums of two, remain constant for sums of three, and rise again for sums of five. Any exceptions to this seem to be attributable to different values for Mondays. Even if the estimates of the characteristic exponent are adjusted upward slightly to account for the downward bias with smaller sample sizes found by Fama and Roll, the tests of stability appear inconclusive.

In general, the results offer the following conclusions: (1) while consecutive daily data do not reasonably conform to processes that are either normal or non-normal stable, day of the week data, within reasonable bounds, seem to be adequately described by a series of stable distributions; (2) any assumption that daily foreign exchange data are normally distributed is most likely grossly in error; (3) Monday price changes conform less well to this (stable) generalization than other days; and, (4) the differences in the nature of the (stable) distributions by day of the week is due to significant differences in the location of the distribution with less effect attributable to differences in dispersion (scale), with no substantive differences in the characteristic exponent. Importantly for practitioners, care should be taken in using the standard deviation as a means of estimating foreign exchange risk. Exchange risk might be more appropriately measured by calculating the scale parameter assuming the existence of a stable distribution.

C. Weekly Price Changes

Statistics for weekly price change intervals, similar to those in Tables IV and V for day of the week observations are presented in Tables VIII and IX. The location parameters on average should be approximately five times the sum of the location estimates from day of the week calculations. Scale parameters also will be affected, though characteristic exponents, being normalized, will not be. Some differences occur that are caused by the influence of holidays on the observation set.

With the possible exception of the British pound, the weekly distributions conform even more closely to the stable distribution. Chi-square tests reject the normal but not the non-normal stable distribution.[12] Tests of stability in Table X show some tendency for the characteristic exponent to rise under addition, but never to 2.0. For sums of one and two, the calculations are remarkably similar to those of Westerfield [33, 34]—as shown in the last row of Table X—who studied similar currencies over a slightly longer period of flexible and fixed exchange rates.

The additional conclusion emanating from the analysis of weekly data is that

[12] Kruskal-Wallis tests of location show no hint of differences among these weekly periods—which would have to be the case given that weekly observations accumulate returns over the other four days as well—and were eliminated to save space.

Table VII

Tests of Stability For Days of the Week, Chronological Ordering Method

	Monday				Tuesday				Wednesday				Thursday				Friday			
Currency	1	2	3	5	1	2	3	5	1	2	3	5	1	2	3	5	1	2	3	5
BP Spot	1.19	1.43	1.10	1.79	1.19	1.20	1.08	1.44	1.20	1.17	1.21	1.14	1.29	1.22	1.32	1.76	1.19	1.18	1.07	1.59
Forward	1.28	1.48	1.18	2.00	1.26	1.49	1.14	1.29	1.33	1.17	1.21	1.14	1.37	1.35	1.41	1.57	1.10	1.30	1.16	1.64
GM Spot	1.47	2.00	2.00	2.00	1.36	1.44	1.67	1.65	1.36	1.57	1.39	2.00	1.42	1.65	1.73	2.00	1.53	1.51	1.57	1.94
Forward	1.52	2.00	2.00	2.00	1.32	1.55	1.64	1.72	1.38	1.33	1.39	1.75	1.38	1.78	1.49	1.67	1.49	1.55	1.57	2.00
JY Spot	1.18	1.26	1.23	1.97	1.10	1.08	1.20	1.22	1.16	1.20	1.30	1.46	1.04	1.09	1.35	1.41	1.09	1.27	1.22	1.43
Forward	1.12	1.36	1.26	1.75	1.11	1.13	1.51	1.37	1.28	1.31	1.15	1.45	1.10	1.26	1.11	1.28	1.19	1.29	1.25	1.38
SF Spot	1.11	1.51	2.00	1.90	1.23	1.58	1.76	1.28	1.37	1.37	1.21	1.42	1.37	1.47	1.29	1.42	1.12	1.26	1.41	1.84
Forward	1.13	1.39	2.00	1.75	1.22	1.57	1.85	1.20	1.35	1.29	1.15	1.34	1.41	1.40	1.19	1.20	1.19	1.23	1.29	1.92
AD Spot	1.33	1.52	1.77	1.93	1.48	1.51	.130	1.52	1.45	1.64	1.97	1.88	1.58	1.56	1.37	1.53	1.39	1.43	1.37	1.47
SP Spot	1.24	1.37	1.35	2.00	1.24	1.36	1.07	1.06	1.09	1.30	1.09	1.34	1.24	1.24	1.47	1.51	1.31	1.27	1.24	1.49
SK Spot	1.28	1.58	1.39	1.93	1.42	1.42	1.56	1.60	1.41	1.21	1.33	1.26	1.26	1.56	1.42	1.19	1.37	1.49	1.44	1.29

Avg. by Currency	Estimates for sums of: 1	2	3	5
BP Spot	1.21	1.24	1.16	1.54
Forward	1.27	1.36	1.22	1.53
GM Spot	1.43	1.63	1.70	1.92
Forward	1.42	1.64	1.62	1.83
JY Spot	1.11	1.18	1.26	1.50
Forward	1.16	1.27	1.26	1.45
SF Spot	1.24	1.44	1.53	1.57
Forward	1.26	1.38	1.50	1.48
AD Spot	1.45	1.53	1.56	1.67
SP Spot	1.22	1.31	1.24	1.48
SK Spot	1.35	1.45	1.43	1.45
Mean	1.29	1.40	1.41	1.58

Avg. by day of the week	Estimates for sums of: 1	2	3	5
Monday	1.26	1.54	1.57	1.91
Tuesday	1.27	1.39	1.43	1.40
Wednesday	1.31	1.32	1.31	1.47
Thursday	1.31	1.42	1.38	1.50
Friday	1.28	1.34	1.34	1.64
Mean	1.29	1.40	1.41	1.58
Mean, corrected for bias	1.29	1.42	1.45	1.64

Table VIII

Parameter Estimates for Stable Distribution for Weekly Data

	Location[a]					Scale[a]					Characteristic Exponent					
Sample Currency	M–M	T–T	W–W	T–T	F–F	M–M	T–T	W–W	T–T	F–F	M–M	T–T	W–W	T–T	F–F	Avg
British pound																
Spot	2.035	5.642	1.012	2.744	4.857	45.167	41.670	46.699	42.889	46.791	1.29	1.32	1.34	1.32	1.27	1.31
Forward	3.980	6.791	1.435	4.961	7.647	54.125	49.786	53.473	55.228	52.431	1.36	1.37	1.45	1.51	1.31	1.40
German mark																
Spot	16.880	12.572	12.095	11.969	14.169	52.568	47.679	56.118	44.099	52.160	1.30	1.27	1.50	1.32	1.32	1.34
Forward	15.890	12.163	11.588	10.701	11.591	57.272	45.649	54.208	44.086	50.728	1.37	1.25	1.44	1.32	1.27	1.33
Japanese yen																
Spot	10.054	9.432	7.632	8.582	11.970	39.344	43.323	42.874	42.552	42.515	1.06	1.15	1.21	1.29	1.20	1.28
Forward	10.919	10.501	8.559	10.557	13.332	41.486	44.818	47.966	49.762	50.496	1.08	1.16	1.17	1.39	1.27	1.21
Swiss franc																
Spot	22.926	18.680	17.326	17.418	16.589	72.797	73.270	70.237	60.891	58.047	1.28	1.35	1.45	1.30	1.16	1.31
Forward	22.895	18.310	16.287	17.460	16.783	68.614	75.315	71.926	63.140	61.999	1.23	1.36	1.46	1.31	1.19	1.31
Australian dollar																
Spot	2.032	1.761	1.347	.939	.575	25.336	26.761	27.853	24.004	24.399	1.50	1.54	1.60	1.55	1.58	1.55
Spanish peseta																
Spot	2.135	1.687	1.148	1.642	2.433	22.695	22.785	25.022	24.780	21.375	1.29	1.18	1.25	1.29	1.21	1.24
Swedish krona																
Spot	3.960	5.383	4.527	5.146	5.202	42.378	38.592	36.414	35.705	33.304	1.28	1.28	1.35	1.33	1.29	1.31

[a] Values are reported in U.S. dollars × 10,000 for all currencies except the Japanese yen and the Spanish peseta. The yen and peseta are reported in U.S. cents × 10,000.

Table IX

Chi-Square Values for Tests of Normal and Stable for Weekly Data[a]

	Normal					Stable				
	Chi-Square Statistic					Chi-Square Statistic				
Sample Currency	M–M	T–T	W–W	Th–Th	F–F	M–M	T–T	W–W	Th–Th	F–F
British pound										
Spot	92.42*	71.00*	50.38*	78.66*	81.34*	31.34*	18.28+	21.82*	36.06*	24.61*
Forward	65.75*	54.39*	34.72*	41.13*	66.82*	12.81	21.22*	10.38	11.80	20.25*
German mark										
Spot	53.75*	60.90*	29.96*	55.21*	37.50*	9.41	10.36	10.58	11.38	4.57
Forward	45.23*	69.42*	35.63*	50.43*	33.01*	7.39	12.83	11.59	9.85	4.94
Japanese yen										
Spot	96.93*	60.06*	63.31*	75.75*	68.72*	13.16	11.09	14.10	16.74+	10.11
Forward	93.89*	54.26*	61.77*	36.47*	63.31*	18.40+	12.79	8.90	8.09	9.05
Swiss franc										
Spot	34.43*	20.96+	40.86*	61.11*	78.33*	7.62	4.21	6.78	11.38	9.80
Forward	49.63*	17.25+	36.12*	67.95*	66.40*	8.75	4.26	5.38	12.46	8.42
Australian dollar										
Spot	31.43*	17.10+	12.29	22.92*	23.85*	11.00	4.62	5.10	7.87	9.35
Spanish peseta	62.91*	34.09*	45.67*	42.96*	83.68*	11.81	12.76	10.08	13.50	14.76
Spot										
Swedish krona										
Spot	32.67*	49.66*	52.29*	38.59*	45.75*	4.35	10.06	13.89	6.36	13.24

[a] Asterisk indicates significance at 1% level and plus indicates significance at 5% level.

Table X

Tests of Stability For Weekly Exchange Rates, Chronological Ordering Method

	Monday				Tuesday				Wednesday				Thursday				Friday			
Currency	1	2	3	5	1	2	3	5	1	2	3	5	1	2	3	5	1	2	3	5
BP Spot	1.29	1.64	1.86	2.00	1.32	1.53	1.85	1.58	1.345	1.45	1.58	1.50	1.32	1.36	1.75	1.94	1.27	1.61	1.13	1.54
Forward	1.36	1.67	2.00	2.00	1.37	1.57	1.87	1.81	1.45	1.51	1.83	1.74	1.51	1.42	1.60	2.00	1.31	1.52	1.25	1.64
GM Spot	1.30	1.30	1.53	1.12	1.27	1.35	1.26	1.44	1.50	1.47	1.32	2.00	1.32	1.58	1.70	1.58	1.32	1.48	1.39	2.00
Forward	1.37	1.34	1.60	1.15	1.25	1.38	1.26	1.49	1.44	1.37	1.31	2.00	1.32	1.49	1.63	1.64	1.27	1.44	1.55	2.00
JY Spot	1.06	1.41	1.35	1.59	1.15	1.31	1.36	1.46	1.21	1.21	1.39	1.40	1.29	1.33	1.38	1.47	1.09	1.27	1.22	1.26
Forward	1.08	1.30	1.29	1.59	1.16	1.33	1.42	1.43	1.17	1.27	1.45	1.35	1.39	1.38	1.45	1.34	1.27	1.38	1.21	1.29
SF Spot	1.28	1.38	1.33	1.33	1.35	1.13	1.42	1.38	1.45	1.18	1.10	2.00	1.30	1.29	1.39	1.12	1.16	1.46	1.76	2.00
Forward	1.23	1.33	1.29	1.38	1.36	1.12	1.45	1.43	1.46	1.16	1.16	2.00	1.31	1.49	1.39	1.17	1.19	1.40	1.59	2.00
AD Spot	1.50	1.49	1.58	2.00	1.54	1.46	1.79	2.00	1.60	1.72	1.64	2.00	1.55	1.49	2.00	2.00	1.58	1.55	1.65	1.89
SP Spot	1.29	1.10	1.51	1.49	1.18	1.05	1.01	1.29	1.25	1.26	1.07	1.31	1.29	1.16	1.12	1.40	1.21	1.24	1.04	1.47
SK Spot	1.28	1.32	2.00	1.78	1.28	1.49	1.32	2.00	1.35	1.37	1.39	1.79	1.33	1.25	1.29	1.28	1.29	1.14	1.35	1.64

Avg. by currency across days	Estimates for sums of: 1	2	3	5
BP Spot	1.31	1.52	1.63	1.71
Forward	1.40	1.54	1.71	1.84
GM Spot	1.34	1.44	1.44	1.63
Forward	1.33	1.40	1.47	1.66
JY Spot	1.18	1.32	1.33	1.44
Forward	1.17	1.27	1.26	1.45
SF Spot	1.31	1.29	1.40	1.57
Forward	1.31	1.25	1.38	1.60
AD Spot	1.55	1.54	1.73	1.98
SP Spot	1.24	1.16	1.15	1.39
SK Spot	1.31	1.31	1.47	1.70
Mean	1.32	1.37	1.46	1.63

Avg. by day, across currencies	Estimates for sums of: 1	2	3	5	10
Weekly rates					
M to M	1.28	1.39	1.58	1.58	
T to T	1.29	1.34	1.46	1.57	
W to W	1.38	1.36	1.39	1.74	
Th to Th	1.36	1.36	1.52	1.54	
F to F	1.28	1.42	1.37	1.70	
Mean,	1.32	1.37	1.46	1.63	
Mean, corrected for bias	1.32	1.39	1.50	1.69	
Mean, corrected for bias[a]	1.27	1.35		1.29	1.49

[a] The figures are from J. Westerfield [34] for the currencies of Canada, Great Britain, West Germany, Switzerland, and the Netherlands. Westerfield's weekly data covers the period January 1962 to July 1975.

weekly observations seem to be reasonably well characterized by non-normal stable distributions. Thus, while it is likely that some more complex compound process generates price changes within a day, and from day to day (since there was evidence of different distributions for different days of the week), the process cycles adequately within a week to suggest that over weekly intervals, foreign exchange price changes in general follow a non-normal stable distribution that is somewhat different from currency to currency.

VI. Conclusions

This study has investigated the distributional properties of a set of major and minor foreign exchange markets on a daily basis. The conclusions suggest that different 24 hour and 72 hour trading intervals corresponding to different days of the week are characterized by different probability distributions. Price changes on Monday and Wednesday suggest a higher price for dollar denominated foreign currencies than exists on Thursday and Friday. The Wednesday and Thursday changes can be explained by the particular institutional structure of the clearing mechanism. The Friday and Monday price changes are less easily explained, but are not inconsistent with a flow into the dollar by the time Friday's price is reported and an outward flow by the time Monday's price is reported.

All day of the week distributions are highly non-normal but conform fairly closely with stable distributions having a characteristic exponent of about 1.4. Differences in the day of the week distributions basically depend on different values for the location parameter, with Monday distributions slightly more disperse. There are few differences in the distributions among the different currencies studied, or between spot and forward markets. Major and minor markets seem to have approximately the same distributional properties. Distributions of weekly price changes also conform closely to non-normal stable distributions; this supports the prior work of Westerfield [33, 34] and suggests that standard deviations calculated from sample observations should be used with caution in assessing the extent of risk associated with holding foreign exchange.

Importantly, these conclusions suggest that consecutive daily data do not conform to any simple process, but must be characterized by a more complex generating scheme such as that described in Equation (1). Thus, daily data should be used with extreme caution for financial research in exchange markets. Finding daily effects generally tends to augment recent research of stock market data that also finds significant daily effects.

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