The Efficiency of the U. S. Dollar Index Futures Market

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INTRODUCTION

The U. S. Dollar Index (USDX) is composed of ten major foreign currencies and expressed in an index form relative to the base value of 100 as of March 1973. The unique feature of the USDX is the weighting of the component foreign currencies included in the index, and the method by which the index is computed. In contrast to other indexes, the USDX is computed as in *inverse value weighted geometric* average of ten major foreign exchange (FX) rates, whereby each FX rate receives a different weight in the index as determined by the Federal Reserve Board in 1973. These weights reflect the relative importance of each foreign country in trading with the U. S. since 1973. Although there have been tremendous changes in international trade since 1973, such as the emergence of Japan and West Germany as the dominant countries in international trade, the weights of the component FX rates in the USDX remain the same.

USDX futures contracts have been traded on the Financial Instrument Exchange (FINEX), a division of the New York Cotton Exchange since November 20, 1985. The USDX futures contracts are traded in a three-month cycle where delivery is on the third Wednesday of the expiring contract month. The futures contract size is \$500 times the contemporaneous USDX spot value. Any futures contracts held to expiration are subject to cash settlement, based on the difference between the USDX value and the USDX futures price times \$500 on the last day of trading for an expiring contract.

As an *inverse geometric average index*, the USDX suffers from a peculiar problem, namely, an *upward bias* to the index relative to what is obtained with arithmetic averaging. Another nonstandard property of the USDX emanates from the fact that as an inverse geometric index, it is expressed in "European terms" (i.e., FX rates per U. S. dollars) rather than quoted in the conventional "American terms" (i.e., U. S. dollars per FX rates). As a result, the USDX rises when the dollar appre-

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ciates in value, and declines when the dollar depreciates. The *upward bias* embedded in the USDX is documented first by Redfield (1986) who uses a rule-of-thumb methodology to estimate the magnitude of the USDX drift which he refers to as the "volatility premium." Relying on Redfield's intuition, Eytan, Harpaz, and Krull (1988), hereafter EHK, use the Black and Scholes (1973), Merton (1973), and Black (1976) contingent claims methodology to explore the determinants and magnitude of the USDX *upward drift*. They show that the USDX drift factor depends not only on the volatility of the index, but on the weighted average volatility of the component *FX* rates. EHK also contend that the upward drift factor embedded in the USDX affects the pricing of its derivative futures contracts. More specifically, they also provided preliminary empirical estimates of the drift's magnitude and conjecture (but do not conduct any statistical tests) that the failure of the market to account properly for the upward drift factor in the pricing of USDX futures may cause market inefficiency.

The objective of this study is twofold: to examine whether investors in the market place incorporate the correct *upward drift* in the pricing of USDX futures contracts; and, to use the daily settlement prices of USDX futures contracts traded on the FINEX for the period November 20, 1985 through December 31, 1988 to test for the efficiency of the FINEX market by employing the EHK futures pricing formula as a benchmark. The rest of the article is organized in three sections. The methodology for the proposed statistical tests and the description of the data set are presented in the second section. The results of the empirical tests are discussed in the third section. The last section contains the conclusion.

METHODOLOGY

The Proposed Statistical Tests

EHK (1988) proposed a USDX futures formula that shows that the *theoretical* USDX futures price is given by

$$F_e(t,T) = I(t)\exp[\bar{r} - r_{us} + \delta)(T - t)], \tag{1}$$

where $F_e(t,T)$ is the USDX futures model price in period t for expiration in period T; $I(t)$ is the contemporaneous USDX spot value as of period t; $\bar{r} = \Sigma_{i=1}^{10} w_i r_i$ is the weighted average foreign risk free rate of interest; r_i and w_i are the ith country risk-free rate of interest and its weight in the index, respectively; r_{us} is the U. S. riskfree rate of interest; $T - t$ is the time left to expiration of the futures contract; and δ is the (positive) "drift" parameter (which is unobservable) which corrects for the upward bias effect due to the (inverse) geometric configuration of the USDX. For the empirical tests, one needs to estimate the *implied* (drift parameter), δ_a, which can be extracted from (1) as follows:

$$\delta_a = \ln[F_a(t,T)/I(t)]/(T - t) - (\bar{r} - r_{us}), \tag{2}$$

where F_a is the *historical* USDX futures price. While the *implied delta* (2) is derived from the EHK futures pricing formula, the "true" delta is unfortunately unobservable. To conduct tests for market efficiency it is necessary to develop an alternative estimate of the "true" delta, the *historical delta*.

The *historical drift parameter,* δ_h, as proposed by EHK, is computed from historical variances,

$$\delta_h = \left[\sum_{i=1}^{10} w_i\sigma_i^2 + \sigma_I^2\right]/2 = [\bar{\sigma}^2 + \sigma_I^2]/2, \tag{3}$$

where σ_i^2 and σ_I^2 are the variances of the rate-of-change on ith FX, and the contemporaneous USDX, respectively; while $\bar{\sigma}^2$ is the weighted average variance of the representative FX included in the index. Clearly the historical delta (δ_h) must be positive. The implied and historical deltas are both estimates of the "true" delta. If the market for the USDX futures contracts is efficient and the EHK model is correct, then the *implied* drift factor (δ_a) will equal the true delta, and also be an efficient and unbiased estimator of the subsequent volatilities on the component currencies and the USDX contract.

In addition, there should be no systematic difference between δ_a and δ_h, and if $\delta_a \neq \delta_h$, no mechanical trading rule should produce profits after transaction costs. Note that while F_a is the historical USDX futures price, F_e is the USDX model price from (1) using the historical delta, δ_h, in (3) as an estimate for the "true" but unobservable delta.

An explicit test for the efficiency of the FINEX market is based on the strategy proposed by EHK (1988). This strategy calls for either long-long or short-short positions in the USDX futures contracts and its component FX forward contracts. Specifically, on each day t for which the USDX futures contract is incorrectly valued ($\delta_a \neq \delta_h$), one long (short) position in the USDX futures contract is combined with 10 long (short) positions in each of the underlying forward contracts, for undervalued (overvalued) contracts, respectively. The investment in the ith FX forward contract if $w_i[F_a(t,T)/f_i(t,T)]$ where $f_i(t,T)$ is the ith currency forward price at time t for fast delivery at time T. Finally, all the positions are offset at expiration.[1] The combined profit $\pi(t,T)$ of the long-long (short-short) hedge portfolio over the contract life (t,T) is given by:

$$\pi(t,T) = (I(T) - F_a(t,T)) + \sum_{i=1}^{10}[w_i I(T)/f_i(t,T)](S_i(T) - f_i(t,T)), \tag{4}$$

where $S_i(T)$ is the spot exchange rate of currency i at the time T. Clearly, for the short-short arbitrage strategy the profit is given by $-\pi(t,T)$. In the absence of margin requirements, the initial investment in the hedge portfolio is zero, and given the null hypothesis that the USDX futures market is efficient, one expects the arbitrage profits $\pi(t,T)$ in (4) (for all contracts) to be zero.

In the first set of tests, incorrectly valued portfolios are identified as follows. For a particular contract j and for each day t over its life span the delta ratio $G_{j,t} = (\delta_h/\delta_a)_{j,t}$ as well as the mean value, μ_G, and the standard deviation, σ_G, are computed for all contracts from day 1 until day $t - 1$. If the USDX futures contract is *persistently* mispriced, then the mean delta ratio, μ_G, will be different from 1.0. Therefore, to test for the degree of mispricing of a particular contract j, its delta ratio, G_j, is compared to 1.0. In addition, to reduce potential sample sensitivity-related problems the range of $1 \pm \sigma_G$ is used.

If δ_a is too low (high), then the actual futures price is too low (high), G will be high (low) and the USDX futures price undervalued (overvalued). Specifically, contract j on day t is defined as being undervalued (UV) if $G_{j,t} > (1 + \sigma_G)$; overvalued (OV) if $G_{j,t} < (1 + \sigma_G)$; and correctly valued (CV) if $(1 - \sigma_G) \leq G_{j,t} \leq (1 + \sigma_G)$. For each and every incorrectly valued (IV) contract the arbitrage strategy stipulated by (4) is applied to estimate the profit (π) in dollars per contract. If the arbitrage profits are significantly different from zero, the hypothesis that the FINEX

[1]It should be emphasized that the hedge position is a long-long or short-short hedge rather than the conventional long-short hedge, because the USDX futures price is quoted in "European terms" whereas the component FX forward prices are expressed in "American terms."

market is efficient can be rejected. In other words, this procedure examines whether *historical* and *implied* deltas differ substantially, and whether trading profits can be earned when such large differences occur.

An alternative and consistent method for identifying incorrectly valued contracts is to compute the incorrect-valuation coefficient based on the *futures price* ratio rather than on the *delta* ratio. Similarly, for a particular contract j and for each day t over its life span the ratio $V_{j,t} = (F_a/F_e)_{j,t}$ is computed, where F_a and F_e are the *historical USDX futures price* and the corresponding *model price which incorporates the historical delta in (3)*, respectively. In addition, the mean value, μ_V, of the V ratio, and the standard deviation, σ_V, across all contracts preceding the evaluation day t are computed. Similar to the delta investment decision rule, contract j on day t is defined as being undervalued (UV) if $V_{j,t} < (1 - \sigma_V)$; overvalued (OV) if $V_{j,t} > (1 + \sigma_V)$; and correctly valued (CV) if $(1 - \sigma_V) < V_{j,t} \leq (1 + \sigma_V)$. Thus, if the V ratio is "too high" ("too low") then the USDX futures contract is overvalued (undervalued).

DATA

The data for this study[2] consist of daily USDX spot and nearby futures settlement prices as well as the component currencies' daily spot and forward settlement prices for the period November 20, 1985 (inception date) through December 31, 1988.[3] It should be emphasized that 1985 includes only 26 trading days.

The daily USDX spot values represent the settlement prices at 2:40 p.m., the close of the USDX market. Individual daily FX spot and forward prices are the settlement prices as of 1:00 p.m.[4] This study uses only nearby futures contracts since they are the most liquid and actively traded. The nearby contract usually accounts for at least 75% of the volume and open interest. In total, the number of nearby contracts examined is 13, and the number of observations (or trading days) is 739.

As indicated by (1) the estimation of the USDX futures model price requires the estimation of the drift factor (delta) and the interest-rate differential ($\bar{r} - r_{us}$). The historical delta has been estimated from (3). The most recent 40 daily observations preceding the evaluation date used to estimate the variance of the rate of change of the spot FX rate of country i, σ_i^2, and the variance of the contemporaneous spot USDX, σ_I^2. The interest rate differential ($\bar{r} - r_{us}$) is estimated using the (assumed) Interest-Rate Parity Theorem (IRPT) as follows:

$$\bar{r} - r_{us} = \sum_{i=1}^{10} w_i r_i - r_{us} = \sum_{i=1}^{10} w_i \ln[S_i(t))/f_i(t,T)]/(T - t), \tag{5}$$

where $S_i(t)$, and $F_i(t,T)$ are the spot FX rate, and the contemporaneous forward price of country i as of period t, respectively. This estimate for the interest rate differential ($\bar{r} - r_{us}$) is used also for computing the implied delta (δ_a) in (2).

[2]The data were provided by Richard Jacobs and June Furlan of the FINEX.

[3]As implied by the magnitude of the riskless arbitrage profit reported in the following section, employing settlement rather than bid or ask prices, and incorporating transaction costs would not change the main conclusions regarding the efficiency of USDX futures contracts.

[4]It should be noted that this lack of synchronization may cause an additional random error.

EMPIRICAL RESULTS

Historical vs. Implied Deltas

The statistical properties of the actual and implied delta, as computed from (3) and (2), respectively, are presented in Table I, and illustrated in Figure 1. The values of both the historical drift factor (δ_h) and the implied delta, (δ_a) are positive and statistically significant for the whole time period 1985–88 as well as for each of the individual years. The statistical significance level is much higher for the δ_h than for the δ_a. This difference reflects the lower dispersion for δ_h than for δ_a, which can be seen very clearly in both Figure 1 and the gap between the maximum and minimum values reported in Table I. This discrepancy is consistently lower for δ_h than for δ_a. Over the whole time period investigated, the mean value for the historical delta (δ_h) is 1.19% as compared with a mean value of 2.58% for the implied delta (δ_a). Note that if the ratio of the two mean values is lower (greater) than 1, it may indicate overvaluation (undervaluation) of the USDX futures contracts. A closer inspection of the intertemporal behavior of the delta ratio reveals that it consistently increases

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...h the "historical price" (F_a). The statistical characte
presented in Table II. Consistent with the behavior of the
price ratio (F_a/F_e) (as well as the mean price difference F_a
undervaluation in 1985 followed by *overvaluation* in 1986 and
correct valuation in 1988. The mean value of ($F_a - F_e$) for t
1985–88 is 0.0879 (and is statistically different from zero) wh
years the mean values are −0.2012, 0.0990, 0.1686, and 0.025
and 1988, respectively. The incorrect valuation coefficient,
picted in Figure 2 and shows many positive values in the 198
trasted with random fluctuations around the zero value in 19

It is apparent from the behavior of both the delta ratio (δ_h/
(F_a/F_e) that the market for USDX futures is *undervalued* fo
overvalued in 1986 and 1987, while almost *correctly* valued in
indicate that, given the incorrect valuation phenomenon w
USDX futures market in 1986 and 1987; it is possible to cons
less arbitrage strategy. The ability of this strategy to generate
vestigated next.

Table I
STATISTICAL PROPERTIES OF HISTORICAL VS. IMPLIED DELTAS (δ_h AND δ_a)*
IMBEDDED IN THE UDSDX FUTURES PRICES (NOVEMBER 20, 1985–DECEMBER 31, 1988)

	Mean	Sdv	Min	Max	*SE*	*t*-value	*N*
1985–8							
δ_h	0.0119	0.0066	0.0033	0.0353	0.0002	49.09	739
δ_a	0.0258	0.0949	−0.5985	1.5787	0.0035	7.39	739
1985							
δ_h	0.0006	0.0005	0.0053	0.0080	0.0001	58.42	26
δ_a	0.0002	0.0036	−0.0084	0.0064	0.0007	0.22	26
1986							
δ_h	0.0129	0.0042	0.0069	0.0234	0.0003	46.64	232
δ_a	0.0370	0.1162	−0.1119	1.3484	0.0076	4.85	232
1987							
δ_h	0.0122	0.0057	0.0038	0.0255	0.0004	33.52	245
δ_a	0.0304	0.1096	−0.5986	1.5787	0.0070	4.34	245
1988							
δ_h	0.0113	0.0089	0.0033	0.0353	0.0006	19.40	236
δ_a	0.0129	0.0456	−0.4857	0.2678	0.0030	4.35	236

*The historical and implied δ_h and δ_a are computed from eqs. (3) and (2), respectively.

Mean = Mean value; Sdv = Standard deviation; Min = Minimum value; Max = Maximum value; *SE* = Standard error of the mean; *t*-value = Mean/*SE*; *N* = Number of observations.

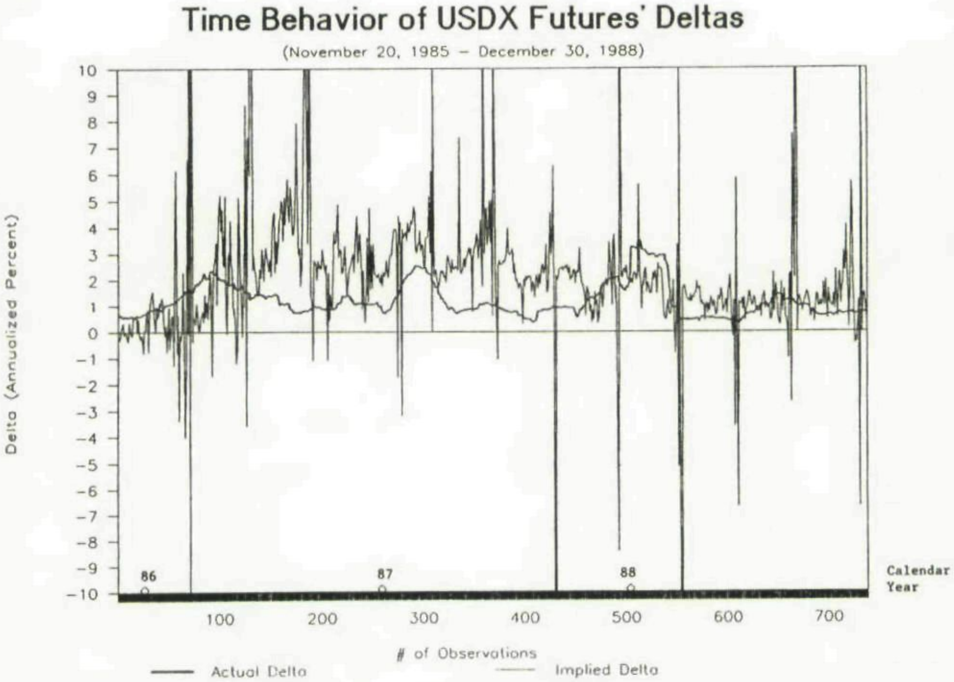

Figure 1

Historical and implied deltas are estimated from eqs. (3) and (2), respectively.

Trading Test Results

The long-long trading strategy stipulated by (4) is applied for each day in which an incorrectly valued (IV) contract, (i.e., undervalued (UV) or overvalued (OV)), is found. Note that incorrect valuation is based on the difference between the implied and the historical δ's. If a particular USDX futures contract is undervalued (overvalued), a long (short) position is taken in the USDX futures contract and 10 long (short) positions in the contemporaneous component FX forward contracts. The positions are offset at expiration. The trading profits in dollars per contract (π) are presented in Table III, and are plotted as a frequency distribution in Figure 3. Over the entire sample of 739 daily observations, 165 contracts are identified as overvalued, and 65 contracts as undervalued. Only 2 contracts are found incorrectly valued for 1988. For the whole period of 1985–88, the mean trading profit is $194.25 and significantly greater than zero. The percentage of positive π's obtained for all the incorrectly valued contracts is 76%. A similar proportion is found for both the undervalued and overvalued contracts over the entire time period. The frequency distribution of the trading profits per contract is depicted in Figure 3.

A closer inspection of Table III reveals that the year by year results are substantially different from each other. In 1985, when the USDX contract began trading, most of the daily observations (18 out of a total of 26) are incorrectly valued. Moreover, these 18 incorrectly valued contracts are all *undervalued*, and *all* of them result in positive trading profits with mean π of $539.50. The relatively high positive trading profit in 1985 is a result of investors failure to incorporate the drift factor (delta) in the pricing of USDX futures contracts. In 1986, the incorrect-valuation phenomenon is less severe than in 1985, and most of the incorrectly-valued con-

Table II
STATISTICAL PROPERTIES OF HISTORICAL VS. MODEL USDX FUTURES PRICES—F_a AND F_e (NOVEMBER 20, 1985–DECEMBER 31, 1988)*

	Mean	Sdv	Min	Max	SE	t-value	N
1985–8							
F_a	101.51	10.28	85.66	128.86	0.3782	268.37	739
F_e	101.42	10.31	85.62	129.09	0.3793	267.39	739
F_a/F_e	1.0008	0.0028	0.9788	1.0230	0.0001	7.48	739
$F_a - F_e$	0.0879	0.1872	−0.7752	0.6197	0.0009	12.7711	739
1985							
F_a	126.19	1.05	123.55	128.86	0.21	615.48	26
F_e	126.39	1.02	123.96	129.09	0.20	632.38	26
F_a/F_e	0.9984	0.0010	0.9967	1.0001	0.0002	−8.40	26
$F_a - F_e$	−0.2012	0.1219	−0.4099	0.0142	0.0239	−8.42	26
1986							
F_a	112.27	5.36	104.24	125.18	0.35	319.10	232
F_e	112.17	5.48	104.05	125.09	0.36	311.60	232
F_a/F_e	1.0010	0.0022	0.9932	1.0057	0.0001	6.62	232
$F_a - F_e$	0.0990	0.2414	−0.7752	0.6197	0.0159	6.25	232
1987							
F_a	97.15	3.64	85.66	104.84	0.2322	418.34	245
F_e	96.98	3.57	85.62	104.59	0.2282	425.04	245
F_a/F_e	1.0013	0.0040	0.9788	1.0230	0.0003	5.14	245
$F_a - F_e$	0.1686	0.1371	−0.1618	0.4488	0.0088	19.26	245
1988							
F_a	92.74	3.37	86.30	99.32	0.22	422.16	236
F_e	92.71	3.37	86.30	99.32	0.22	422.41	236
F_a/F_e	1.0003	0.0012	0.9961	1.0035	0.0001	3.58	236
$F_a - F_e$	0.0251	0.1059	−0.3460	0.3228	0.0069	3.64	236

*The model price F_e is computed from eq. (1), based on the historical delta in (3).

Mean = Mean value; Sdv = Standard deviation; Min = Minimum value; Max = Maximum value; SE = Standard error of the mean; t-value = Mean/SE; N = Number of observations.

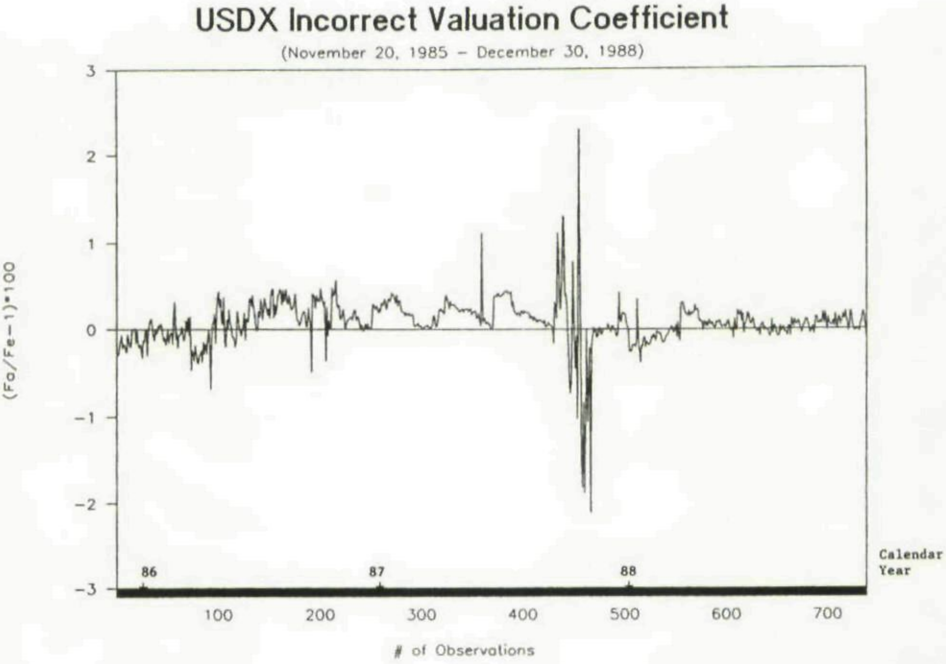

Figure 2

The incorrect-valuation coefficient is equal to $(F_a/F_e - 1)100$, where F_a and F_e are the historical and model prices from eq. (1), respectively. Note that the model price F_e in (1) is based on the historical delta in (3) as an estimate for the true but unobservable delta.

tracts are *overvalued*. The mean profit (π) on the riskless trading strategy ($210.95) is significantly positive, and 79% of all π values are positive. This overvaluation phenomenon continued in 1987 with an average significant profit of $113.80, except that the proportion of positive π's decreases from 79% in 1986 to 68% in 1987. In contrast to 1985, 1986, and 1987, the mispricing phenomenon is corrected in 1988. This result expresses the intertemporal behavior of the degree of mispricing of the USDX futures contract. The existence of almost no incorrectly valued contracts in 1988 indicates that the USDX futures contracts are fairly priced and as a result no positive riskless trading profits could be generated. Thus, the hypothesis that the USDX futures market is efficient in 1988, cannot be rejected.[5]

CONCLUSION

Using the EHK (1988) USDX futures pricing formula, several statistical tests are performed to test for efficienty of the USDX futures contracts during the period 1985–88. Using daily settlement prices for nearby futures contracts traded on the FINEX from the inception of the contract 1985 through 1988, the null hypothesis that the USDX futures market is efficient in this time period is rejected. It is shown that positive trading profits can be obtained if one applies a long-long (short-short) arbitrage strategy to undervalued (overvalued) contracts. This trading strategy comprises a long (short) position in the USDX futures contract and ten long (short) po-

[5]An early, but incomplete investigation of the first three months of 1989 also shows no mispricing of the USDX futures contract.

Table III
TRADING PROFITS IN DOLLARS PER CONTRACT (π)* ON INCORRECTLY VALUED USDX FUTURES CONTRACTS (NOVEMBER 20, 1985–DECEMBER 31, 1988)

	Mean	Sdv	Min	Max	*SE*	*t*-value	*N*	% Pos	% Neg
1985–8									
IV	194	303	−783	1,012	20	9.74	230	76	24
UV	264	366	−704	1,012	45	5.82	65	78	22
OV	167	268	−783	852	21	7.97	165	75	25
1985									
IV	539	210	194	971	49	10.91	18	100	0
UV	539	210	194	971	49	10.91	18	100	0
OV	—	—	—	—	—	—	0	—	—
1986									
IV	211	299	−783	1,012	29	7.34	108	79	21
UV	63	348	−704	1,012	62	1.02	32	59	41
OV	986	1,522	783	852	175	5.65	76	87	13
1987									
IV	114	276	−555	896	27	4.17	102	68	32
UV	375	291	−136	896	78	4.82	14	93	7
OV	72	249	−555	554	27	2.72	88	64	36
1988**									
IV	290	—	—	—	—	—	2	100	0
UV	185	—	—	—	—	—	1	100	0
OV	395	—	—	—	—	—	1	100	0

*π is given by eq. (4), and it is the dollar profit on the hedge portfolio over contract life.

**Not all values for 1988 are given since only 2 observations were found incorrectly valued, and they both yield highly positive returns.

Mean = Mean value; Sdv = Standard deviation; Min = Minimum value; Max = Maximum value; *SE* = Standard error of the mean; *t*-value = Mean/*SE*; *N* = Number of observations; *IV* = Incorrectly valued contracts; *UV* = Undervalued portfolio contracts; *OV* = Overvalued contracts; % Pos = Percentage of positive π; % Neg = Percentage of negative π.

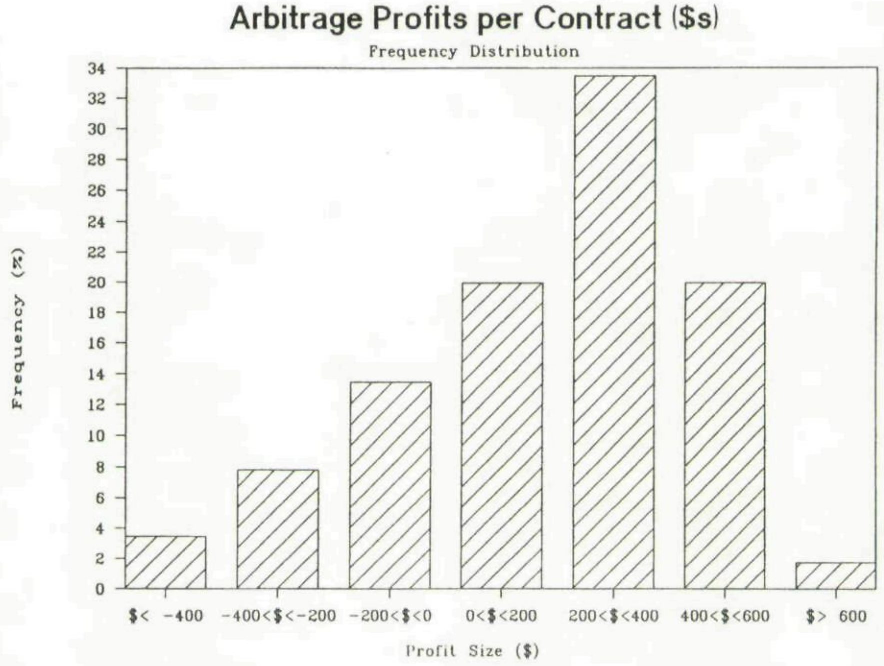

Figure 3

The trading profits in dollars per contract are computed from eq. (4) for the period November 20, 1985 through December 31, 1988. Note that in 1988 only 2 observations were found incorrectly valued.

sitions in the component forward contracts and offsetting the positions at expiration. The USDX futures contract was clearly *undervalued* in the 26 trading days of 1985 but in 1986 and 1987 it was *overvalued*. In 1988 it was correctly priced. The incorrect valuation is a result of investors not properly accounting for the positive drift parameter (delta) stipulated by the pricing of the USDX futures contracts. The presence of the positive drift factor (delta) is embedded in the USDX futures contracts because of the *inverse geometric* averaging of the ten foreign exchange rates included in the index. Since 1988, investors have properly incorporated the 'true' drift parameter (delta) in their pricing and this has resulted in the correct valuation of USDX futures contracts.

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