THE TERM STRUCTURE OF VOLATILITY IN THE TURKISH FOREIGN EXCHANGE: IMPLICATIONS FOR OPTION PRICING AND HEDGING DECISIONS

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Abstract

This paper is a first effort to describe the term structure of volatility in foreign exchange market of a developing country, namely Turkey. Realized volatility and implied volatility under random walk hypothesis are compared by employing daily observations of the U.S. dollar and German mark against Turkish lira for the period July 1981 to December 1995. The paper reports that volatility increases slower (faster) than the square root of time in the short (long) term, reflecting significant deviance from random walk hypothesis. Thus, weak form efficiency is rejected. Rescaled range (R/S) analysis asserts that exchange rate volatility is anti-persistent or mean reverting. Possible implications of the empirical results for option pricing and hedging decisions are also discussed.

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Key words: Turkish foreign exchange, term structure of volatility, informational efficiency, option pricing, hedging currency risk.

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I. INTRODUCTION

Volatility in financial markets has always been a key element in investment decisions and modelling financial markets. Financial market volatility has recently been investigated, among others, by Shiller (1989), Turner and Weigel (1990), Scott (1991), and Peters (1994). However, resources, in general, seem to have been devoted to studies concerning developed financial markets. The present paper attempts to investigate foreign exchange market volatility in a developing country, namely Turkey. Since we deal with volatility with respect to the efficient markets hypothesis (EMH), our paper can also be considered as a test of the EMH.

The informational efficiency of the Turkish foreign exchange was previously tested in a number of studies. Among these, Culbertson (1989), using monthly data for the period 1957 to 1983, did not reject weak form of the EMH for Turkey. Employing standard autocorrelation tests and filter rules, Aydoğan (1990) did not reject weak form efficiency in the black market for foreign exchange using weekly data for the period September 1985 to August 1987. Altınkemer (1992) rejected the EMH for weekly data. Using autocorrelation tests and cointegration, Abaan (1995) rejected both weak form and semi-strong form efficiency in the Turkish foreign exchange employing daily data from official and parallel markets for the period January 1987 to December 1992. A similar analysis was due to Yüce (1996). Aydoğan and Booth (1996) provided evidence for calendar anomalies in the Turkish foreign exchange. Aysoy and Balaban (1996) reported significant deviance from the EMH applying rescaled range (R/S) analysis for currency returns. Balaban and Kunter (1996) found that developments in foreign exchange market can be predicted by using changes in market liquidity. In addition, foreign exchange market, interbank money market and stock market were found pairwise interdependent.

II. DATA AND METHODOLOGY

This study is based on Peters' (1994: 27-31) work on the term structure of volatility in the U.S. stock market. The same methodology was used by Balaban (1995) for the Turkish stock market. Peters (1994) tests whether volatility measured by standard deviation scales according to the square root of time. This scaling of volatility is derived from brownian motion, a primary model for a random walk process. Einstein's (1908) work on brownian motion finds that the distance that a random particle covers increases with square root of time used to measure it. In Peters' (1994: 55) work, this is formulated as follows:

$$R = T^{0.5} \tag{1}$$

where R and T denote the distance covered and a time index, respectively. The so-called *T to the one-half rule* is extensively used in financial economics to find, say, annual volatility given standard deviation of, say, monthly returns. Peters (1994: 27), among others, notes that annualized risk is simply found by multiplying the standard deviation of monthly returns by the square root of 12.

Daily observations of the U.S. dollar and German mark against Turkish lira provided by the Central Bank of the Republic of Turkey (CBRT) range between July 2, 1981 to December 29, 1995. We use average of bid-ask prices offered by the CBRT. Daily logarithmic returns on each currency that amount to 3,600 observations are calculated as follows:

$$R_t = \log (X_t / X_{t-1}) \tag{2}$$

where X_t and R_t denote Turkish lira per foreign currency and return on that currency on day *t*, respectively. Then, each foreign currency return series is divided into series of subperiods, ${}_iY_T$, such that

$$n_i \times T_i = N \tag{3}$$

where n_i and T_i refer to the number and length of subperiods in series *i*, respectively. The length of the total sample size, *N*, is 3,600. ${}_iY_T$ refers to the i^{th} series where the subperiods have a length of *T*. Thus, 43 different series are constructed; i.e., i = 1, 2, 3, ..., 43. In these series, the associated *T* values are as follows: 1, 3, 4, 5, 6, 8, 9, 10, 12, 15, 16, 18, 20, 24, 25, 30, 36, 40, 45, 48, 50, 60, 72, 75, 80, 90, 100, 120, 144, 150, 180, 200, 225, 240, 300, 360, 400, 450, 600, 720, 900; 1,200; and 1,800 days. Note that these *T* values can also be considered as investment horizon. The *T*-day returns for the contiguous subperiods are also calculated in the same way. Upon completion of the construction of the return series in the way described above, descriptive statistics is calculated for each ${}_iY_T$. The special emphasis is put on the standard deviation. Note that the calculated standard deviations for each investment horizon indicate realized volatility for that horizon.

Implied volatility under random walk hypothesis is derived according to the *T to the one-half rule* as follows:

$$SD_T = SD_1 \times T^{0.5} \tag{4}$$

where SD_T refers to the standard deviation of *T*-day returns. SD_1 is daily volatility; i.e., T is equal to one. For each series, implied volatility is calculated in the same way. Note that the realized daily volatility is taken as base point in calculation of all *T*-day implied volatility.

Percentage difference between realized volatility and implied volatility for each *T*-day series is computed to emphasize deviations, if any. In addition, coefficient of variation and studentized range are calculated to see how standardized volatility changes through time. Finally, the following regression is run to test whether the realized volatility increases by the square root of time:

$$\log SD_T = \beta \times \log T \quad (5)$$

Note that the null of random walk is rejected if β significantly differs from 0.5.

We also apply rescaled range (R/S) analysis for volatility following Peters (1994:147).

We run the following regression:

$$\log (R/S)_T = H \times \log T \quad (6)$$

where H is Hurst exponent which ranges between zero and one. Note that H = 0.5 implies that the series investigated follows random walk. If $0.5 < H \leq 1$, the series is said to be persistent. If H $0 \leq H < 0.5$, the series is considered as anti-persistent or mean-reverting.

III. EMPIRICAL RESULTS

Table 1 and *Table 2* provide summary statistics with respect to different investment horizons for the U.S. dollar and German mark, respectively. Note that mean returns for both currencies increase proportionately with time, as expected. What is also expected is that volatility must increase at *some* rate to be compatible with the risk-return relationship. It is well known in financial literature that investors must bear higher risk to obtain higher return. However, this is not observed behavior in the Turkish foreign exchange. Investors seem to bear higher risk for lower returns, and vice versa, for different holding periods. *Figure 1* and *Figure 2* show realized and implied volatility.

Table 3 and *Table 4* compare realized and implied volatility across investment horizons and present such standardized measures of dispersion as coefficient of variation and studentized range. It is expected that realized volatility increases by the square root of time under random walk assumption. Note that realized volatility is different from implied volatility for both currencies for all horizons. A closer investigation asserts that the calculated deviations indicate that the term structure of volatility of both currencies has different characteristics in three components: In the first part where holding period is between 1 and 16 days, implied volatility is always greater than realized volatility. If holding period is between 18 and 120 days, difference between realized and implied volatilies is relatively small. In addition, it is difficult to assert a definite pattern for the term structure of volatility. In the third part where holding period is greater than 120 days, realized volatility is generally higher than implied volatility.

Coefficient of variation and studentized range, in general, tend to inversely change with the length of investment horizon; i.e., they both decrease as investment horizon becomes longer. This result implies that long-term investors face less risk per unit of return and less risk per unit of volatility compared to short-term investors.

Table 5 and *Table 6* present regression results for the so-called *T to the one-half rule* for the U.S. dollar and German mark, respectively. This is done first by considering all holding periods, and then, for three different ranges of holding period. We find a β of 0.51518 and 0.51640 for the U.S. dollar and German mark, respectively, if all holding periods from one day to 1,800 days are considered. This means that volatility of the returns on the U.S. dollar and German mark increases by the 1.94 (1/0.51518 and 1/0.51640) root of time. These statistically significant results indicate that the term structure of volatility of both currencies is not consistent with the EMH; i.e., currency returns show a higher risk level than the EMH asserts. However, this conclusion may be *misleading* if different nature of holding period ranges are not carefully investigated.

It should be noted that in the first range where holding period is between one and 16 days, β for both currencies is lower than 0.5. In other words, volatility of the returns on the U.S. dollar and German mark increases by the 2.54 (1/0.39357) and 2.45 (1/0.40769) root of time, respectively. This implies that holding periods less than or equal to 16 days are *less riskier* than the level asserted by the random walk model. For the U.S. dollar, volatility is consistent with the EMH for the holding period between 18 and 120 days since we find β = 0.50810 which does not significantly differ from 0.5. In this case volatility increases by the 1.97 root of time. On the other hand, β for German mark for the same range is significantly higher than 0.5. In this case, volatility increases by the 1.93 (1/0.51741) root of time. Finally, in the third range where holding period is longer than 144 days, β for both currencies is higher than 0.5. Volatility of the returns on the U.S. dollar and German mark increases by the 1.89 (1/0.52856) and 1.91 (1/0.52487) root of time, respectively. This implies that holding periods longer than days are *riskier* than the EMH asserts.

Table 7 provides the results of R/S analysis of volatility for the U.S. dollar and German mark. We find H is equal to 0.36577 and 0.37046 for the U.S. dollar and German mark, respectively. These results imply that volatility in the Turkish foreign exchange is anti-persistent or mean reverting.

IV. CONCLUSION AND IMPLICATIONS

The primary contribution of this paper is that the term structure of volatility in the Turkish foreign exchange does not seem consistent with the implications of random walk hypothesis. In addition, the results differ for three ranges of holding period. In the short term, both the U.S dollar and German mark returns are less volatile than random walk model asserts. A major reason for this may be the intervention by the Central Bank of the Republic of Turkey (CBRT). In our opinion, the CBRT frequently intervenes to the foreign exchange market to prevent large fluctuations. This is crucial for Turkish investors as well as other economic agents since currency substitution in Turkey has been extremely high, particularly in recent years. In the medium term, the U.S. dollar volatility is consistent with the random walk assumption whereas volatility of German mark is higher compared to random walk. In the long-term, both currencies are more volatile than random walk. The primary reason for this can be again the CBRT intervention. However, it works differently. Since the CBRT intervenes into the foreign exchange market to manage short-term fluctuations or to achieve other goals, exchange rates deviate from purchasing power parity (PPP) in the short-run. In the long run, they tend to converge to PPP.

However, adjustment process towards PPP becomes more volatile. In our opinion, frequent and heavy CBRT intervention aiming at managing short-term fluctuations seem leading to higher fluctuations in exchange rates in the long run.

The results of R/S analysis show that volatility in the Turkish foreign exchange is anti-persistent or mean reverting. This implies that a higher-than-mean increase in volatility in a period is followed by a decrease in volatility in the next period. This is consistent with the findings of Aysoy and Balaban (1996) who conclude that currency returns are persistent for the same period.

IV.1. Implications for Option Pricing

The empirical results of the paper have some implications for option pricing and hedging exchange risk. We first focus on pricing currency options. Black and Scholes (1973) developed in their seminal paper an option pricing formula for common stocks which has been extensively used by academicians as well as practitioners. The Black-Scholes formula modified for currency options can be expressed as follows (see, for example, Garman and Kohlhagen (1983)):

$$C = S\, e^{-R(T-t)} N(d_1) - K\, e^{-r(T-t)} N(d_2) \qquad (7a)$$

$$P = K\, e^{-r(T-t)} N(d_2) - S\, e^{-R(T-t)} N(d_1) \qquad (7b)$$

where

$$d_1 = \{ln(S/K) + (r - R + \sigma^2/2)\, t\} / \sigma\, t^{0.5} \qquad (7c)$$

$$d_2 = \{ln(S/K) + (r - R - \sigma^2/2)\, t\} / \sigma\, t^{0.5} = d_1 - \sigma\, t^{0.5} \qquad (7d)$$

In above equations, C and P are call and put prices, respectively, for an European option on currency. Domestic and foreign risk-free interest rates are denoted by r and R, respectively. S is current exchange rate whereas K is exercise price. Time to maturity, in years, is shown by t. N(.) is the cumulative probability distribution function. Annualized volatility or standard deviation is indicated by σ. Note that all variables except volatility are directly observable in market. On the other hand, volatility, a direct input in option pricing formula, must be estimated.

Among the assumptions of the Black-Scholes formula,[1] we focus on that for volatility. In (7a) and (7b), it is assumed that exchange rates follow geometric Brownian motion where standard deviation grows by square root of time. As discussed previously, the term structure of volatility in the Turkish foreign exchange is not in accordance with the above assumption. Clearly speaking, random walk model overestimates (underestimates) volatility in the short (long) term. Note that there is a *positive* relationship between call/put option price and volatility in the Black-Scholes formula. Therefore, if volatility in the foreign exchange market is estimated according to random walk model or if standard deviation of exchange rates is assumed to grow by the square root of time, the Black-Scholes formula overvalues (undervalues) short (long) term options on the U.S. dollar and German mark. This mispricing may lead to arbitrage opportunities by simply, say, writing a short term call option and buying a long term put option with the same features except time to maturity.

[1] Since we put a special emphasis on volatility, our aim is not to deal with the other features of the Black-Scholes formula. For excellent books on options as well as pricing methods including the Black-Scholes formula, see Cox and Rubinstein (1985) and Hull (1993), among others. For testing option pricing models, see Bates (1995).

In our opinion, these implications for pricing currency options in Turkey are more appealing in recent times than ever before. It should be noted that the Capital Markets Board is working on a project to establish a market for currency futures and options market as well as other derivative securities. In addition, the Istanbul Securities Exchange is also working on introduction of derivative markets in the near future.

IV.2. Implications for Hedging Currency Risk

Academics and practitioners in the field of finance mostly agree that international diversification pays. However, currency risk is crucial for investors who diversify internationally. This is more important if there are no derivative securities to hedge exchange risk. Even if there exist hedging opportunities, its effectiveness depends on some factors. If forward premium/discount is equal to expected change in currency, hedged and unhedged returns become equal. In this case, effectiveness of hedging is dependent on the following factors: exchange rate volatility (σ_x), volatility of foreign asset in local currency (σ_i), and degree of correlation between volatilities of exchange rate and foreign asset ($\rho_{x,i}$) (see, for example, Benari (1991)). Hedging exchange risk is effective or necessary if

$$\rho_{x,i} > -\sigma_x / 2\sigma_i \tag{8}$$

holds.

Benari (1991) expresses the right hand side of (8) as volatility index. Note that if correlation between currency and foreign asset is positive, hedging is always effective. If exchange rate and foreign asset are negatively correlated, effectiveness of hedging depends on the value of volatility index. Ceteris paribus, if exchange rate volatility increases, so does effectiveness of hedging. Therefore, underestimate of exchange rate volatility may lead to a decision not to hedge. Similarly, overestimated volatility may give a signal for hedging although it is unnecessary.

Using the above methodology, Balaban and Candemir (1995) find that foreign investors who diversify in the Turkish stock market should hedge their investments. This result is valid for daily and monthly changes of the U.S. dollar and German mark against Turkish lira for the period to January 1988 to July 1995.

Table 1. Summary Statistics: U.S. Dollar

T	n	Mean	Standard D.	Max.	Min	Range
1	3,600	0.18	0.98	32.85	-11.54	44.39
3	1,200	0.33	1.50	34.67	-17.18	51.85
4	900	0.50	1.33	15.59	-13.26	28.84
5	720	0.71	2.21	48.87	-16.93	65.80
6	600	0.88	2.17	39.47	-6.98	46.44
8	450	1.20	1.66	13.62	-5.49	19.11
9	400	1.41	2.84	44.96	-12.28	57.24
10	360	1.57	3.01	46.95	-4.97	51.92
12	300	1.95	3.22	43.68	-7.25	50.92
15	240	2.40	2.73	27.06	-3.80	30.86
16	225	2.56	2.49	15.43	-3.57	19.00
18	200	3.03	3.89	42.64	-5.03	47.67
20	180	3.33	4.65	52.30	-4.87	57.18
24	150	4.13	4.71	46.85	-2.33	49.18
25	144	4.30	5.10	46.03	-4.43	50.46
30	120	5.05	4.95	39.11	-4.89	44.00
36	100	6.25	6.57	57.70	-3.53	61.23
40	90	6.88	8.13	71.33	-7.40	78.73
45	80	7.56	5.56	38.33	-4.15	42.48
48	75	8.42	8.21	67.02	-4.51	71.53
50	72	8.60	6.80	39.76	-3.12	42.88
60	60	10.31	8.92	63.49	-6.86	70.35
72	50	12.60	11.72	84.56	-4.09	88.64
75	48	12.92	7.67	46.06	2.20	43.86
80	45	13.90	9.33	60.96	2.87	58.09
90	40	15.56	8.08	49.70	3.65	46.06
100	36	17.39	12.10	77.80	4.62	73.18
120	30	20.82	10.53	56.48	7.58	48.90
144	25	25.35	18.16	104.18	10.18	94.00
150	24	26.01	11.83	63.51	9.07	54.44
180	20	31.34	14.82	83.26	14.64	68.62
200	18	34.94	18.18	101.54	14.47	87.07
225	16	39.05	16.02	80.30	16.53	63.77
240	15	41.95	15.84	82.85	18.96	63.89
300	12	52.43	21.08	110.95	27.85	83.10
360	10	62.87	23.19	119.72	35.83	83.89
400	9	70.16	26.18	139.28	50.09	89.19
450	8	78.39	24.94	117.12	41.26	75.86
600	6	105.03	29.60	164.42	75.32	89.10
720	5	126.02	35.40	187.08	78.66	108.43
900	4	157.48	35.83	218.03	125.98	92.04
1,200	3	210.20	49.21	279.40	169.22	110.18
1,800	2	315.32	40.34	355.66	274.98	80.68

All figures except T, length of holding period in days, and n, the number of subperiods, are in percentages.

Table 2. Summary Statistics: German Mark

T	n	Mean	Standard D.	Max.	Min	Range
1	3,600	0.19	1.02	33.18	-12.43	45.61
3	1,200	0.36	1.53	33.75	-17.08	50.83
4	900	0.55	1.45	15.88	-12.35	28.23
5	720	0.78	2.22	47.00	-15.66	62.66
6	600	0.98	2.22	37.45	-11.98	49.43
8	450	1.31	1.79	14.91	-6.27	21.18
9	400	1.51	2.79	42.60	-9.29	51.90
10	360	1.72	2.97	44.92	-3.85	48.77
12	300	2.12	3.22	41.85	-8.87	50.72
15	240	2.58	2.82	26.37	-3.28	29.66
16	225	2.77	2.74	16.92	-3.08	20.00
18	200	3.29	4.00	42.26	-4.73	46.99
20	180	3.66	4.67	51.41	-2.98	54.39
24	150	4.44	4.85	46.66	-2.64	49.30
25	144	4.77	5.20	46.53	-3.02	49.55
30	120	5.53	5.05	39.68	-1.51	41.18
36	100	6.74	6.86	59.70	-5.48	65.17
40	90	7.52	8.07	72.09	-4.91	77.00
45	80	8.21	6.11	40.16	-1.64	41.81
48	75	8.99	8.29	69.43	-0.71	70.13
50	72	9.38	6.69	43.86	-1.64	45.50
60	60	11.29	8.86	66.85	-0.90	67.75
72	50	13.64	12.35	88.42	-0.42	88.84
75	48	14.19	8.49	48.42	1.48	46.94
80	45	15.05	9.79	64.29	3.98	60.31
90	40	16.89	9.23	51.03	3.25	47.79
100	36	18.94	12.42	82.23	2.85	79.38
120	30	22.65	10.66	65.57	6.30	59.27
144	25	27.43	16.89	100.56	7.89	92.67
150	24	28.46	12.18	63.66	6.56	57.10
180	20	33.96	15.52	90.68	12.03	78.64
200	18	37.90	17.65	102.03	11.05	90.98
225	16	42.49	15.08	76.28	17.96	58.32
240	15	45.29	16.37	95.95	25.29	70.66
300	12	56.90	22.92	122.47	32.54	89.93
360	10	68.19	22.08	125.01	39.84	85.16
400	9	75.85	23.51	134.10	51.94	82.17
450	8	85.26	21.81	115.26	53.70	61.55
600	6	113.54	32.92	180.16	79.87	100.29
720	5	136.44	34.02	201.87	104.46	97.41
900	4	170.46	38.71	226.17	123.42	102.75
1,200	3	227.44	48.65	295.95	187.72	108.22
1,800	2	340.93	33.88	374.81	307.06	67.75

All figures except T, length of holding period in days, and n, the number of subperiods, are in percentages.

Table 3. The Term Structure of Volatility: U.S. Dollar

T	Realized Volatility	Implied Volatility	Difference	Coefficient of Variation	Studentized Range
1	0.98			5.44	45.30
3	1.50	1.70	13.46	4.55	34.57
4	1.33	1.97	47.76	2.66	21.68
5	2.21	2.20	-0.58	3.11	29.77
6	2.17	2.41	10.92	2.47	21.40
8	1.66	2.78	67.42	1.38	11.51
9	2.84	2.95	3.80	2.01	20.15
10	3.01	3.11	3.23	1.92	17.25
12	3.22	3.40	5.71	1.65	15.81
15	2.73	3.81	39.40	1.14	11.30
16	2.49	3.93	57.85	0.97	7.63
18	3.89	4.17	7.17	1.28	12.25
20	4.65	4.39	-5.50	1.40	12.30
24	4.71	4.81	2.20	1.14	10.44
25	5.10	4.91	-3.67	1.19	9.89
30	4.95	5.38	8.73	0.98	8.89
36	6.57	5.90	-10.26	1.05	9.32
40	8.13	6.21	-23.56	1.18	9.68
45	5.56	6.59	18.55	0.74	7.64
48	8.21	6.81	-17.08	0.98	8.71
50	6.80	6.95	2.18	0.79	6.31
60	8.92	7.61	-14.67	0.87	7.89
72	11.72	8.34	-28.86	0.93	7.56
75	7.67	8.51	10.95	0.59	5.72
80	9.33	8.79	-5.80	0.67	6.23
90	8.08	9.32	15.37	0.52	5.70
100	12.10	9.83	-18.79	0.70	6.05
120	10.53	10.95	4.03	0.51	4.64
144	18.16	11.79	-35.07	0.72	5.18
150	11.83	12.03	1.73	0.45	4.60
180	14.82	13.18	-11.05	0.47	4.63
200	18.18	13.90	-23.56	0.52	4.79
225	16.02	14.74	-8.00	0.41	3.98
240	15.84	15.22	-3.90	0.38	4.03
300	21.08	17.02	-19.26	0.40	3.94
360	23.19	18.64	-19.61	0.37	3.62
400	26.18	19.65	-24.94	0.37	3.41
450	24.94	20.84	-16.42	0.32	3.04
600	29.60	24.07	-18.69	0.28	3.01
720	35.40	26.37	-25.52	0.28	3.06
900	35.83	29.48	-17.73	0.23	2.57
1,200	49.21	34.04	-30.83	0.23	2.24
1,800	40.34	41.69	3.34	0.13	2.00

All figures except coefficient of variation and studentized range are in percentages. Positive (negative) difference means implied (realized) volatility is greater than realized (implied) volatility.

Table 4. The Term Structure of Volatility: German Mark

T	Realized Volatility	Implied Volatility	Difference	Coefficient of Variation	Studentized Range
1	1.02	-	-	5.37	44.72
3	1.53	1.78	16.34	4.25	33.22
4	1.45	2.05	41.38	2.64	19.47
5	2.22	2.29	3.15	2.85	28.23
6	2.22	2.51	13.06	2.27	22.27
8	1.79	2.90	62.01	1.37	11.83
9	2.79	3.07	10.04	1.85	18.60
10	2.97	3.24	9.09	1.73	16.42
12	3.22	3.55	10.25	1.52	15.75
15	2.82	3.97	40.78	1.09	10.52
16	2.74	4.08	48.91	0.99	7.30
18	4.00	4.35	8.75	1.22	11.75
20	4.67	4.58	-1.93	1.28	11.65
24	4.85	5.02	3.51	1.09	10.16
25	5.20	5.12	-1.54	1.09	9.53
30	5.05	5.61	11.09	0.91	8.15
36	6.86	6.15	-10.35	1.02	9.50
40	8.07	6.48	-19.70	1.07	9.54
45	6.11	6.88	12.79	0.74	6.85
48	8.29	7.10	-14.35	0.92	8.46
50	6.69	7.25	8.37	0.71	6.80
60	8.86	7.94	-10.38	0.78	7.65
72	12.35	8.70	-29.55	0.91	7.19
75	8.49	8.88	4.59	0.60	5.53
80	9.79	9.17	-6.33	0.65	6.16
90	9.23	9.72	5.31	0.55	5.18
100	12.42	10.25	-17.47	0.66	6.39
120	10.66	11.23	5.35	0.47	5.56
144	16.89	12.30	-27.18	0.62	5.49
150	12.18	12.55	-2.56	0.43	4.69
180	15.52	13.75	-11.40	0.46	5.07
200	17.65	14.49	-17.90	0.47	5.15
225	15.08	15.37	1.92	0.35	3.87
240	16.37	15.88	-3.09	0.36	4.32
300	22.92	17.75	-22.56	0.40	3.92
360	22.08	19.45	-11.91	0.32	3.86
400	23.51	20.50	-12.80	0.31	3.50
450	21.81	21.74	-0.32	0.26	2.82
600	32.92	25.10	-23.75	0.29	3.05
720	34.02	27.50	-19.17	0.25	2.86
900	38.71	30.75	-20.56	0.23	2.65
1,200	48.65	35.50	-27.03	0.21	2.22
1,800	33.88	43.48	28.34	0.10	2.00

All figures except coefficient of variation and studentized range are in percentages. Positive (negative) difference means implied (realized) volatility is greater than realized (implied) volatility

Table 5. Regression Results: U.S. Dollar

	$\log SD_T = \beta \times \log T$			
	$1 \leq T \leq 1{,}800$	$1 \leq T \leq 16$	$18 \leq T \leq 120$	$144 \leq T \leq 1{,}800$
Estimate	0.51518	0.39357	0.50810	0.52856
Standard error	0.00695	0.02758	0.00915	0.00582
t-value [a]	2.184	-3.859	0.885	4.907
R^2	0.992	0.953	0.995	0.998

[a] Calculated *t*-value for difference of β from 0.5.

Table 6. Regression Results: German Mark

	$\log SD_T = \beta \times \log T$			
•	$1 \leq T \leq 1{,}800$	$1 \leq T \leq 16$	$18 \leq T \leq 120$	$144 \leq T \leq 1{,}800$
Estimate	0.51640	0.40769	0.51741	0.52487
Standard error	0.00632	0.02205	0.00813	0.00687
t-value [a]	2.595	-4.186	2.141	3.620
R^2	0.994	0.972	0.996	0.998

[a] Calculated *t*-value for difference of β from 0.5.

Table 7. R/S Analysis of Volatility

	$\log (R/S)_T = H \times \log T$	
	U.S. Dollar	German Mark
Estimate	0.36577	0.37046
Standard error	0.02404	0.01714
t-value [a]	5.583	7.558
R^2	0.842	0.923

[a] Calculated *t*-value for the difference of H from 0.5.

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