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ANALYSIS OF SHORT-RUN EXCHANGE RATE BEHAVIOR

MARCH, 1973 TO SEPTEMBER, 1975

by

Michael P. Dooley and Jeffrey R. Shafer

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I. Introduction

Exchange rates among major foreign currencies have experienced considerable short run variability since the inception of generalized floating exchange rates in March 1973. Exchange rate movements of individual foreign currencies against the U.S. dollar of one-half per cent or more in a single day have been frequent; movements of two per cent or more have occurred on a few occasions. The sentiment that this volatility is evidence of a failure of the floating rate system or a failure of stabilizing speculation is widely held.[1/] In this paper we look at the evidence of the first 30 months of floating rates in order to discover how exchange rates have fluctuated and why. Such knowledge is a precondition for examining what role official intervention might play in exchange markets.

One set of explanations offered for the variability of exchange rates is in terms of the "price dynamics" of the market. The price dynamics view emphasizes the role of perceived price trends in

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* Economists, International Finance Division, Board of Governors of the Federal Reserve System. The views expressed herein are solely those of the authors and do not necessarily represent the views of the Federal Reserve System. Ralph W. Smith coauthored an earlier draft of this paper and made valuable comments on this extention of the research. The authors wish to acknowledge the contribution of Coralia Flaifel to the design and execution of the statistical tests reported in Part III. Katie Meskill and Martha Terrie handled the programming, computation, and preparation of tables and figures. Edwin M. Truman provided helpful comments on an earlier paper. Any remaining errors are the responsibility of the authors.

the formation of exchange traders' expectations. Expectations based on "fundamental factors" are said to be "weakly held" and, hence, traders are unwilling to take large positions on the basis of them. The resulting exchange rate path is interpreted in terms of price runs, bandwagons, and technical corrections. These explanations will be examined in greater detail in Part II.

Another explanation offered for this great (by historical standards) exchange rate variability is that the international monetary system has been subjected to frequent, severe shocks -- rampant world inflation, the fall of governments, the oil crisis, deep and widespread recession, changes in exchange controls, etc. These shocks, it is argued, have resulted in frequent revisions of expectations for future exchange rates. Under this view expectations are again "weakly held" and therefore subject to frequent revision on the basis of small pieces of information, but the market for foreign exchange is "efficient" in taking account of whatever information is available. A weak form of the "efficient market" hypothesis is that all information contained in the past history of exchange rates is reflected in the current rate. Under this hypothesis bandwagons do not occur, and any attempt to profit from projected trends will fail to yield more than a normal rate of return. Under conditions to be elaborated in Part III the expected change in an exchange rate will be zero and the past history of exchange rates will provide no information concerning the expected value of future changes.

In Part III we present statistical evidence on whether the price dynamics view or the weak efficient market view best characterizes exchange markets. Finally, in Part IV we present some implications of our findings and outline the directions that we feel further research in this area should take.

II. The Price Dynamics View

The price dynamics view asserts that prices in speculative markets follow predictable patterns. There are several hypotheses concerning the behavior of market participants which create these patterns. Probably the oldest explanation is the "greater fool" hypothesis.[2/] According to this hypothesis speculators are not concerned with the factors that determine the long-run equilibrium price of a stock, a commodity, or, in the case of exchange markets, a currency. No price is too high as long as a "greater fool" will pay a higher price tomorrow. Once the price begins to move in one direction, it is argued, speculative fever will keep pushing the price in that direction as long as the madness of the crowd is expected to last. The speculation feeds on itself.

The "bandwagon" hypothesis is a variant of the "greater fool" hypothesis. According to this hypothesis a small set of market leaders are known or thought to have more accurate information concerning the factors that will affect future prices. When this set of market participants buy or sell, generating a price change, a signal is provided to other market participants to jump on the "bandwagon". The followers are thought generally to overshoot the new equilibrium price. The price dynamics implied by this hypothesis, therefore, involve successive changes in one direction followed by partial reversals. To quote a prominent British banker-economist:

> Once a currency begins to fall, then the other banks join in the selling pressure, pushing the currency down further. The momentum can gather ground very quickly as the market trend becomes self-fulfilling assuming that no institutions are willing to take the opposite view. And many banks have concluded (quite correctly in the short-term) that by following the pack it is easy to pick up profits; or, if they do not respond to the market movement they are exposed to the danger of serious currency losses. It is only when a currency has fallen (or risen) by a very great amount that the pressure of selling (or buying) stops and is reversed. 3/

The alleged existence of the bandwagon effect has also given rise to the suspicion that exchange rates have been manipulated by a bank or syndicate of banks. The syndicate allegedly takes a position to get a bandwagon rolling, then later jumps off the bandwagon having earned a handsome profit.

Price-dynamics interpretations surfaced repeatedly in the spring of 1973 when the dollar fell very sharply against European currencies, again in the winter as the dollar subsequently appreciated, and yet again during successive swings in dollar exchange rates, particularly vis á vis the German mark and the Swiss franc, in 1974 and 1975. In the first instance, the statement was frequently heard, as the dollar reached successive new lows, that the dollar had fallen to "ridiculously low" levels, levels "unjustified... on any reasonable assessment of the outlook for the U.S. [balance of] payments position."[4/] Traders were reported generally to believe the dollar to be fundamentally undervalued but were unwilling to "buck the market" in the short-run and indeed found themselves jumping on the bandwagon for the short-term ride.

If exchange markets are characterized by price dynamics behavior, there is a clear role for central bank participation in exchange markets. By acting in a more rational manner than private speculators, the central bank could reduce the deviations in market rates from equilibrium rates and make profits at the expense of speculators. Moreover, this could be accomplished with no net change in the average reserve position of the central bank over longer periods. On the other hand, if exchange rates follow random walks, with markets efficiently appraising and adjusting to new information, central bank intervention that was triggered by price movements and that did not result in permanent changes in international reserves would, at best, not change noticeably the evolution of exchange rates. The central bank would in this case supplant some of the activity of private market participants. At worst, central bank intervention would introduce noticeable trends into the evolution of exchange rates and create opportunities for alert private market participants to profit from speculating against the central bank. A dramatic example of this outcome was seen in the final years of the fixed parity system.

III. The Efficient Markets Hypothesis

An alternative to the price dynamics interpretation outlined above is that exchange rate changes are best described as being formed in an "efficient market." In a large number of studies[5/] of prices in markets for equities and for commodities futures, the efficient market characterization has been found to be more consistent with the data than the price dynamics characterization. A strong version of the efficient market hypothesis is that a large and competitive group of market participants have access to all information relevant to the formation of expectations about future prices. As a result, at any time, all relevant information is discounted in the present price.

Under the strong efficient market hypothesis, the history of past price changes is only one of the types of information that are fully exploited. A weaker version of the efficient market hypothesis holds that, while not all information is available to a large number of market participants, any information in past price movements is known to a sufficient number of market participants so that profitable speculation based on such information is impossible. For example, if serial correlation existed in a price series, the recognition of this pattern would generate speculative positions which would break up the pattern.

The weak efficient-market hypothesis is consistent with the existence of some kinds of non-price information to which only a few market participants are privy and on the basis of which those participants may take profitable positions. On the other hand, positions taken on the basis of inside information must be small enough that they not effect the price and, in that way, signal other market participants that conditions had changed. If it were normal, as the proponents of the "bandwagon" hypothesis argue, for bullish information to diffuse slowly among market participants with the result that there were a slowly shifting demand schedule and a slowly rising price, one would only have to watch prices to know that other participants in the market knew something and that it was a good time to buy. Those investors who watched price patterns carefully would find price rises followed by price rises and would bid for a currency as soon as they saw a rise in its price. The result of this process would not be a gradual price increase that overshoots the new equilibrium but an abrupt price change that might be too large or too small in an individual case, but that on average would move the price immediately to the new equilibrium. For if price changes tended to be taken too far, price watchers would take positions to profit on the consistent "technical corrections," and this action would tend to eliminate the overshooting.

The efficient-market hypothesis is widely associated with the empirical hypothesis that prices in the market follow a martingale. A martingale is defined as a statistical process in which the expected value of successive changes are independent of all previous changes. For the efficient market hypothesis to hold, the next price change must not depend on past changes in any way that could lead to profitable position taking based on such a dependence.

We shall first consider a full set of conditions that would generate a martingale in forward exchange rates. This path for forward exchange rates is then related to paths for spot exchange rates. We shall then consider several qualifications that we would expect would cause some deviation from a martingale, but that are consistent with the weak efficient market hypothesis.

If there is a competitive group of market participants whose combined resources are large relative to the size of the market, whose objectives are to maximize the expected dollar values of their portfolios, and to whom the study of price information is costless, the sequence of prices over time of a forward contract for the same specified date in the future will follow a martingale.[6/] This proposition can be illustrated by considering the sequence of prices on a contract to receive foreign currency on September 30. On September 15 the rate on a forward contract for delivery on September 30 must be excctly equal to the rate that is expected to prevail in the spot market on September 30. The expected rate for September 30 reflects full utilization of any information contained in past quotations for value of September 30. Investors, who are assumed to take any fair bet, would offer to buy any amount of the currency forward if their expectation for the September 30 spot rate were above the forward rate. There would be an excess demand for the currency in the forward market. Similarly, any forward rate above the expected future spot rate would be associated with excess supply. Equality must also hold between the forward rate for September 30 on September 15 and the forward rate expected to occur for September 30 on September 16. If not, investors could buy or sell currency for delivery on September 30 and plan to cover on the 16th with an expected profit. There would be an excess demand or supply of forward currency on September 15. Therefore, equilibrium requires that the expected change in the forward rate between September 15 and 16 be zero, regardless of the level of the rate on September 15. On September 16 the actual forward rate will, in general, have changed as new factors affect the market. These factors could not have been predictable, however. The forward rate on September 16 will be exactly equal to the new spot rate that is expected for September 30. The expected future spot rate changes in response to information that is known on September 16 that had not been known on September 15. The same argument applies to each successive day until September 30 -- each day the forward rate changes to reflect new expectations about the spot rate on September 30, but in each case the expected change in the forward rate is zero.

The resulting sequence of prices on successive days for value on a specified future date is a martingale. If, in addition, each price change is determined by the same probability law, it is a random walk. The important respects in which the assumptions of the theoretical model should not be expected to hold are discussed below.

An important qualification to the model outlined above is that market participants may not, in fact, take large forward positions for arbitrarily small discrepancies between the forward rate and a consensus expected spot rate. For any of several reasons -- risk aversion, limited resources, legal limitations on capital movements, or divergent expectations among market participants combined with any of the other reasons --a larger expected gain is required to induce individuals to hold larger open positions. That is, net positions denominated in different currencies are imperfect substitutes for one another. Under these conditions both expected real rates of return and spot exchange rates adjust to clear the market for net assets of all maturities of all currencies. A holder of a forward contract has a net asset position in one currency and a net liability position in another. The expected rate of return on this contract, which is the annualized percentage difference between the expected future spot rate and the forward rate, will be equivalent to the return from holding a security of the same maturity as the forward contract in the currency that one is long and a liability of the same maturity in the currency that one is short. If a higher expected real rate of return is required on foreign currency assets than on dollar assets in order for outstanding supplies of foreign currency assets and dollar assets to be willingly held, the forward rate for the foreign currency will be less than the expected future spot rate by an amount that, when annualized, will be equal to the required premium on the rate of return on foreign currency assets. Successive revisions of expectations concerning what spot rate will prevail on the value date will still have an expected value of zero, but imperfect substitutability and related considerations would lead to predictable daily price changes in forward rates of about .004 per cent for every per cent difference in expected real rates of return required to have stocks of assets denominated in different currencies willingly held. This potentially predictable component would be a very small part of the exchange rate changes observed during the sample period. By comparison, the lowest sample standard deviation of daily per cent changes was .012 (for Canada); the largest was .069 (for Germany).

The statistical work in this paper is based on changes in spot exchange rates rather than on successive forward quotes for the same value date. Interest arbitrage will lead to the equality of <u>covered</u> yields on available instruments of identical payment risk denominated in different currencies. The annualized forward premium on a foreign currency must therefore equal the amount by which the nominal interest rate on assets denominated in that currency falls short of the nominal interest rate on dollar assets. The current spot rate will then differ from the expected spot rate for a given value date by an amount such that the annualized expected appreciation of the currency against the dollar is just equal to the difference between the required premium on the real rate of return for that currency and the amount by which the nominal interest rate on assets denominated in the foreign currency exceeds the nominal dollar interest rate. An expected depreciation will be required if the difference is negative. An expected appreciation or depreciation will, of course, mean that consecutive changes in spot exchange rates will not follow a martingale even if the market is efficient. As an example, assume that equilibrium in international asset markets requires a real rate of return on three month DM assets that is one per cent per year less than the real rate of return required on three month dollar assets. Assume further that the three month nominal interest rate on DM is two per cent above the comparable dollar rate. Equilibrium would then require an expected depreciation of the mark of 1.0 per cent per year vis-á-vis the dollar. The spot exchange rate will be .25 per cent above the spot rate expected to prevail in three months. Expected daily exchange rate changes will have a non zero mean; in this case the mean will be about .004 per cent. The mean of expected exchange rate changes from even much larger interest rate and rate of return differentials will be small when compared to actual changes. We would expect then that departures of spot exchange rates from a martingale due to differences in nominal interest rates to be very small.

The qualifications discussed above apply to the martingale hypothesis but not to the weak efficient-market hypothesis as we have defined it. There are additional qualifications that could lead to the failure of the efficient-market hypothesis as well as the martingale hypothesis, but which can be distinguished from the price dynamics view: Transactions costs, although small, are not zero in exchange markets. Obtaining information and analyzing it are costly. The risks of doing business in exchange markets involve credit risk as well as the risk of exchange-rate changes. Capital controls could cause departure of exchange markets from efficiency, and controls were in effect for some countries during the period we are considering. Finally, if central banks enter the market to smooth exchange rate changes with sufficient resources to outweigh private market participants, they will introduce unusually long runs of exchange rate changes in one direction. Central bank intervention that is large relative to private position taking in exchange markets and that is motivated by other objectives may introduce other systematic patterns in rate changes.

LV. Statistical Evidence on the Behavior of Exchange Rates

Description of the tests

In this section we summarize the results of three sets of tests designed to detect exchange rate behavior that is inconsistent with the weak efficient-market hypothesis and that is consistent with the price-dynamics view. The tests were performed on daily, noon bid rates for foreign currencies in the New York market. Dollar prices for the currencies of Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Switzerland, and the United Kingdom were tested for the period March 13, 1973, to September 5, 1975. This period was also divided into halves and into thirds, and the tests were carried out on the sub-periods in order to look for evolution in market behavior since the floating of the dollar. The currencies of Germany, Belgium and the Netherlands were tied together within a 4 1/2 per cent band in the EC snake during this period and this made their behavior <u>vis-á-vis</u> the dollar in many ways similar. The French franc entered the snake on July 10, 1975.

In order to provide an intuitive sense of the power of the tests, all of the tests carried out on the exchange rate data were also carried out on series constructed using computer-generated pseudo-random variables. Four series that follow martingales with identically distributed error terms (random walks) were constructed. Ten additional series were created that obey the following equation:

$$\text{I.} \quad X_t - X_{t-1} = \alpha (X_{t-1} - X_{t-2}) - \beta (X_{t-1} - \bar{X}) + \epsilon_t$$

where X_t is the logarithm of the hypothetical exchange rate on day t and the ϵ_t are independent, identically, normally distributed random variables with mean zero. This equation is intended to characterize two types of behavior that are hypothesized under the price dynamics view. For values of α between zero and one the hypothetical exchange rate series will exhibit inertia; that is, the exchange rate change today will include a fraction of yesterday's change as well as a new unpredictable component. For values of β between zero and one the hypothetical series will exhibit mean regressiveness; that is, the exchange rate will be pulled back towards its "normal" level whenever unpredictable forces move it away. The martingale hypothesis implies that both α and β are zero. Table 1 gives the assumed parameter values for the hypothetical price dynamics paths.

Table 1

Parameter Values of Pricing Dynamics Paths

Path number	α	β
1,2	.1	.01
3,4	.3	.01
5,6	.1	.05
7,8	.1	.1
9,10	.1	.15

The first set of tests for time dependence of exchange rate changes is based on the sample autocorrelations of changes in the logarithms[7/] of exchange rates for lags up to twenty days. Tests were performed on the autocorrelations taken as a whole and on the values of individual autocorrelations. The price-dynamics view suggests that changes in exchange rates should be correlated with previous changes. This is true of the hypothetical series that obey Equation I and of first differences of more complicated autoregressive-moving-average processes. An absence of autocorrelation would indicate that at least this information has been fully exploited by market participants. If changes in the logarithms of exchange rates were stationary and had a normal distribution, the absence of correlations would be a necessary and sufficient condition for intertemporal independence. If the changes are not stationary or are not normally distributed, the possibility exists for profitable information that is not reflected in autocorrelations to be hidden in prices, but the absence of autocorrelations would rule out the most obvious and the most likely departures from randomness.

The results of the Kolmogorov - Smirnov test[8/] applied to changes in logarithms of exchange rates have led us to reject the hypothesis that daily exchange rate changes are normally distributed. The highest probability of being wrong in rejecting the hypothesis of normality when it is true is 0.1 for Canada.

A comparison of sample density functions with the density function for normal distribution reveals that the tails of the distribution of the changes in logarithms of exchange rates are too fat. Fat tails, which were first focused on by Mandelbrot [1963], appear to be the rule for speculative prices. We explored whether the fat tails were symptomatic of a stable distribution with infinite variance for speculative price changes, as Mandelbrot hypothesized, by examining the behavior of daily, weekly, and monthly exchange rate changes. If daily changes are drawn from any stable distribution with infinite variance, the distribution of changes over longer periods would look no more normal than daily changes. On the other hand, if daily changes are independent draws from any finite variance distribution, the central limit theorem assures that changes over long time periods will be normally distributed. Table 2 shows the value of the Kolmogorov - Smirnov statistic and the probability of wrongly rejecting the hypothesis of normality when it is true. The table shows a clear tendency for sample distributions to be fit better by a normal distribution function the longer the differencing interval.[9/] The test becomes less powerful as the differencing interval increases since fewer observations are obtained, but the declining Z values for longer differencing intervals shows that the rise in the probabilities is not misleading. We have not yet found a theoretical distribution that fits the daily changes well.

That logarithms of daily exchange rate changes seem to have finite variance distributions allows classical statistical theory to be used to evaluate the sample autocorrelations. The resulting tests are useful, but the absence of autocorrelation would not be sufficient for intertemporal independence in and of itself. We have performed a second set of tests of the weak efficient-market hypothesis that do not depend on the distribution of daily changes. The tests examine whether the sequences of signs of exchange rate changes can be distinguished from the sequence of signs that would be generated by tossing a fair coin. The sequence of signs of changes in an exchange rate need not correspond to a coin tossing experiment for there to be no <u>useful</u> information in the history of past prices -- a high probability of an outcome of a particular sign may correspond to a low absolute change so that the expected value of any exchange rate change is zero. On the other hand, a sequence of signs could be generated by a fair coin while gains were possible from knowing about the relative magnitudes of positive and negative changes. These qualifications notwithstanding, tests on the lengths of runs are potentially valuable because they distinguish between the behavior of exchange rates that would be likely in a weakly efficient market and behavior that is hypothesized to characterize exchange rates in the price-dynamics view -- a prevalence of sustained runs (that is, bandwagons) up or down. We report the results of a formal test of the hypothesis that the total

TABLE 2

Kolmogorov-Smirnov Test Applied under Alternative Differencing Intervals

first number -- statistic
second number -- probability of rejecting normality hypothesis when true

	Daily	Weekly	Monthly
Belgium	2.87612724	0.75469846	0.51281631
	.00000012	0.61926353	0.95515078
Canada	1.70169353	0.77971351	0.54473579
	0.00610662	0.57747334	0.92800528
France	3.46679020	1.03714371	0.59300035
	0.0	0.23229146	0.87341326
Germany	2.15015411	1.32010937	0.42773998
	0.00019288	0.06128258	0.99308997
Italy	2.78856468	1.29618931	0.65019238
	0.00000030	0.06945276	0.79171526
Japan	5.34875774	2.08610058	0.95516533
	0.0	0.00033194	0.32118601
Neth	2.46850777	1.04885674	0.52442676
	0.00001013	0.222126079	0.94614261
Switz	2.56890678	0.97953725	0.52435058
	0.00000370	0.29258412	0.94620490
U.K.	2.55964375	1.55418301	0.52926904
	0.00000405	0.01595753	0.94209206

number of runs in an exchange rate series could have been generated by tossing a fair coin. We also consider the incidence of runs of unusual length.

A third set of tests was conducted on the profitability of a class of trading rules, so-called filter rules,[10/] which are profitable if there are bandwagons in exchange markets. An investor following an X per cent filter rule takes a long position in a foreign currency that has risen X per cent from its most recent low point and holds the position until the currency falls by X per cent from the highest level reached since the position was opened. A signal to sell is also a signal to go short. The short position is then closed out on the next buy signal.

The filter tests for five countries were conducted adjusting for interest rate differentials using average interest rates in national money markets for that week and for transactions costs.[11/] A long position in a foreign currency was credited with the daily interest on that currency less the interest that could have been earned in dollars. A short position was debited the interest differential. Currencies were sold at the afternoon bid rate for the day and bought at that rate plus a .1 per cent (.05 per cent for the United Kingdom) premium. The results thus take account of one of the qualifications to the martingale hypothesis for spot exchange rates. As a comparison, the filters were also applied to nine countries without the interest rate adjustment. The filter rules were also applied to the generated random and price-dynamics paths.

A sufficiently exhaustive set of tests would certainly contain one that would lead one to reject the hypothesis of randomness for a set of truly random sequences. Our list of tests is long enough so that one should not put much weight in isolated results. The results of the tests on the pseudo-random series serve to remind us of this. However, as reported in the next section the tests of the autocorrelations taken as a whole, the frequency of significant autocorrelations and the profitability of the filter trading rules suggest some departure from the martingale hypothesis and casts doubt on the weak efficient-market hypothesis.

Results

The autocorrelation evidence is summarized in Tables 3, 4 and 5 and Figures 1 through 32. Sample autocorrelations were calculated for each exchange rate and for the random walk and price dynamics paths for lags up to twenty business days. We tested the first 20 autocorrelations, taken as a whole, in order to determine the adequacy of the martingale model for describing exchange rate changes using a χ^2 test. The Q statistic reported in Table 3 is large when the absolute values of the sums of the autocorrelations is large. The critical values for Q indicate the probability of

FIGURE 1

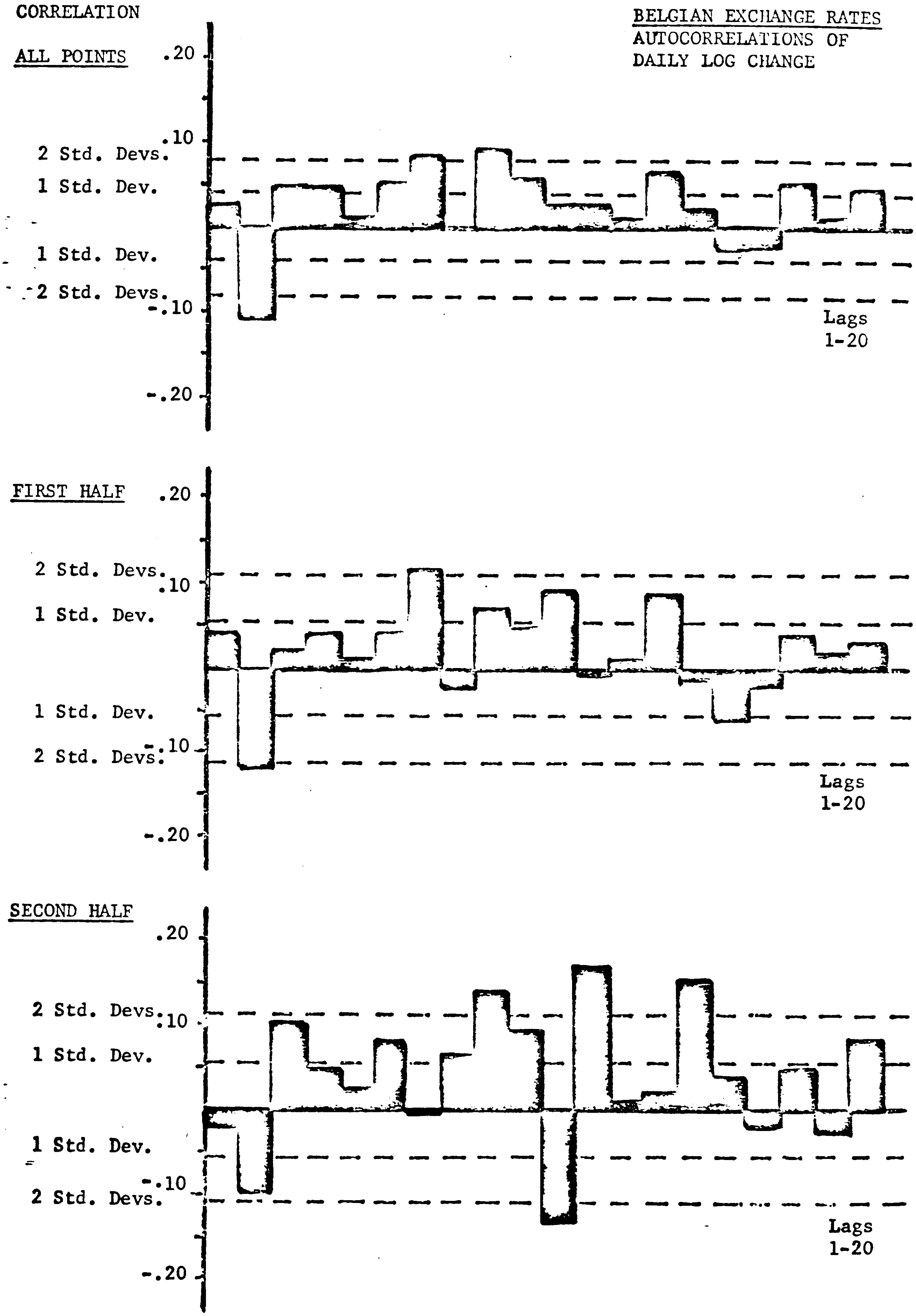
CORRELATION
BELGIAN EXCHANGE RATES
AUTOCORRELATIONS OF
DAILY LOG CHANGE
ALL POINTS
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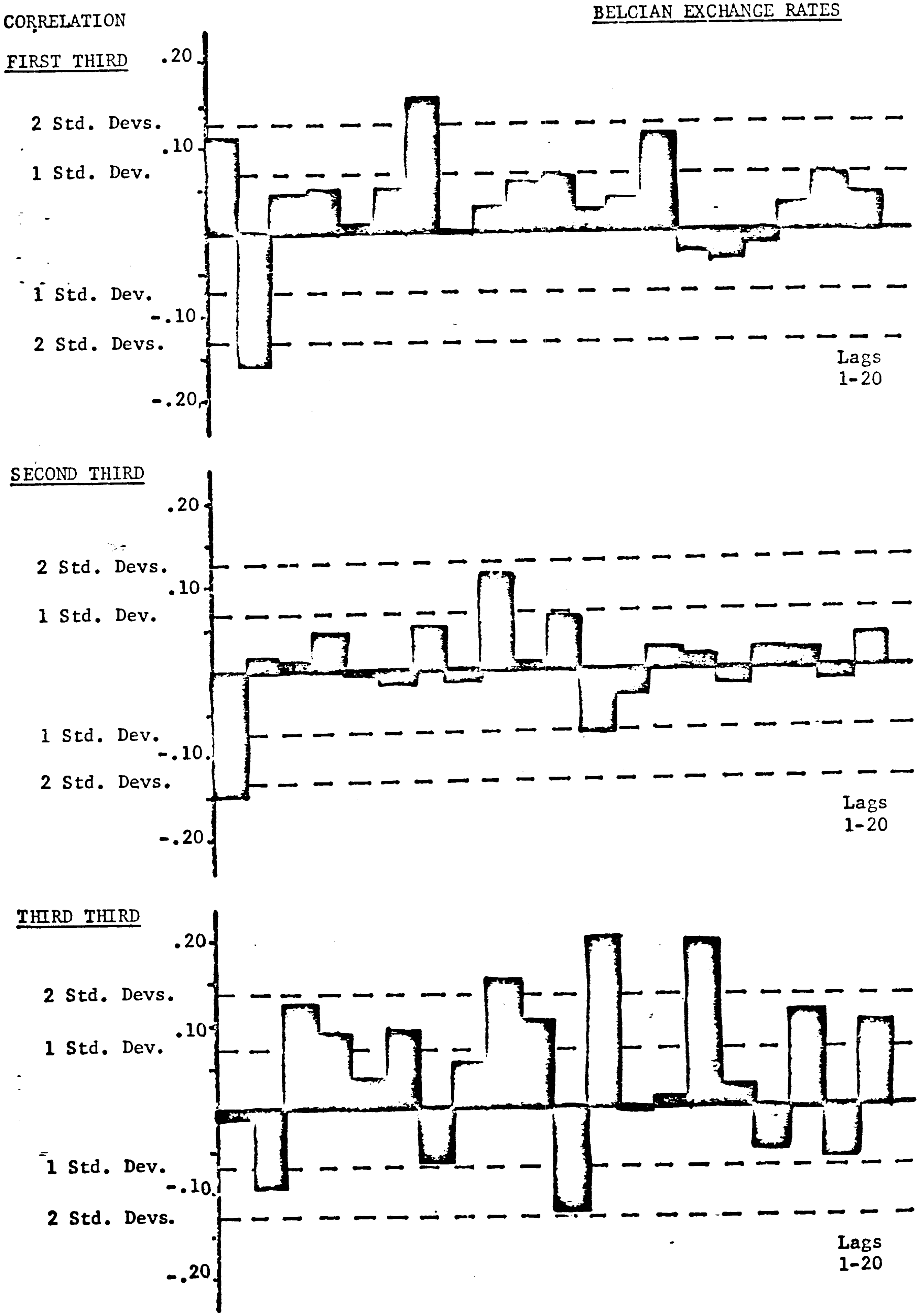
FIGURE 2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BELCIAN EXCHANGE RATES
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FIGURE 3

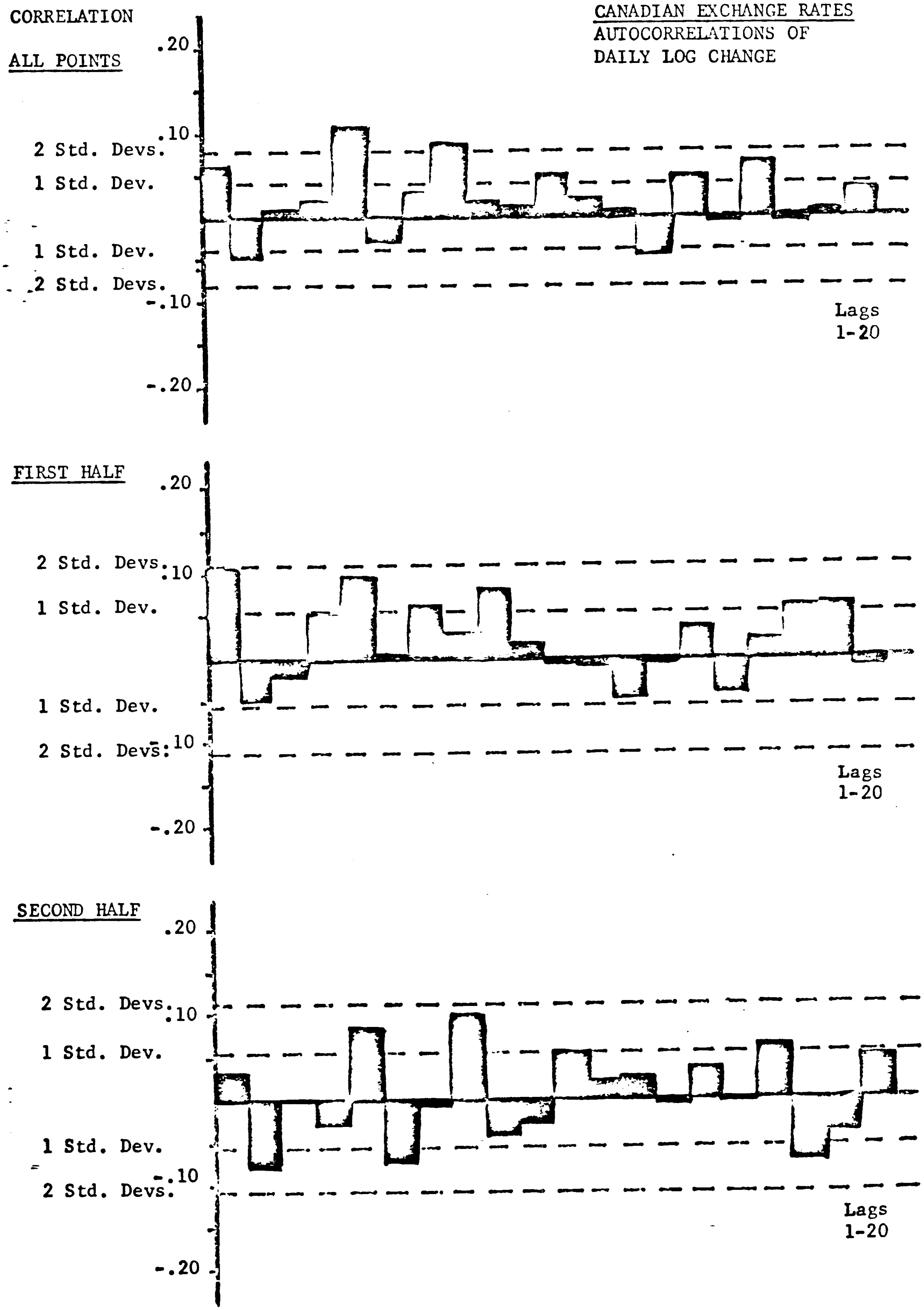
CORRELATION
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FIGURE 4

CANADIAN EXCHANGE RATES

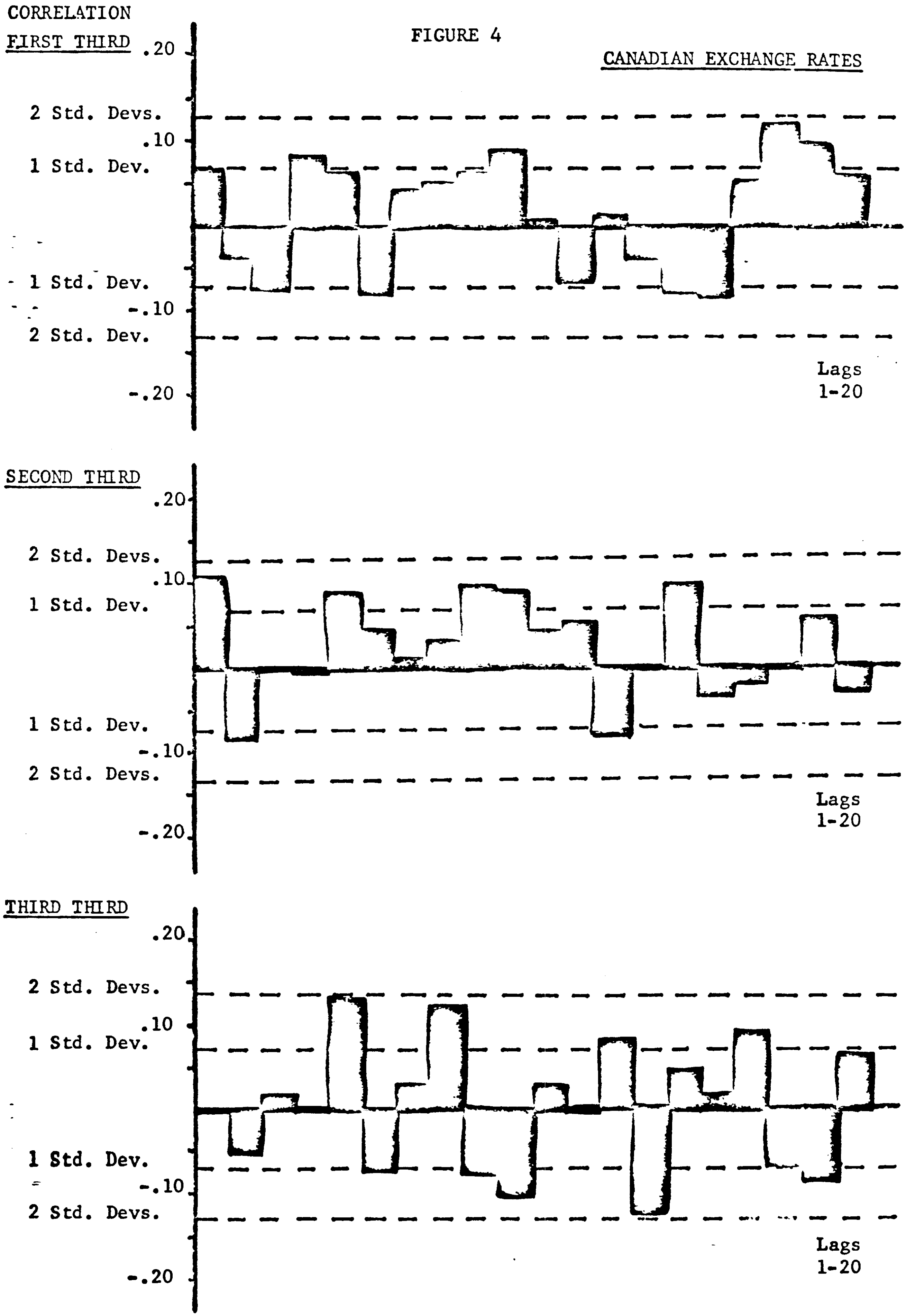

FIGURE 5

FRENCH EXCHANGE RATES
AUTOCORRELATIONS OF DAILY LOG CHANGE

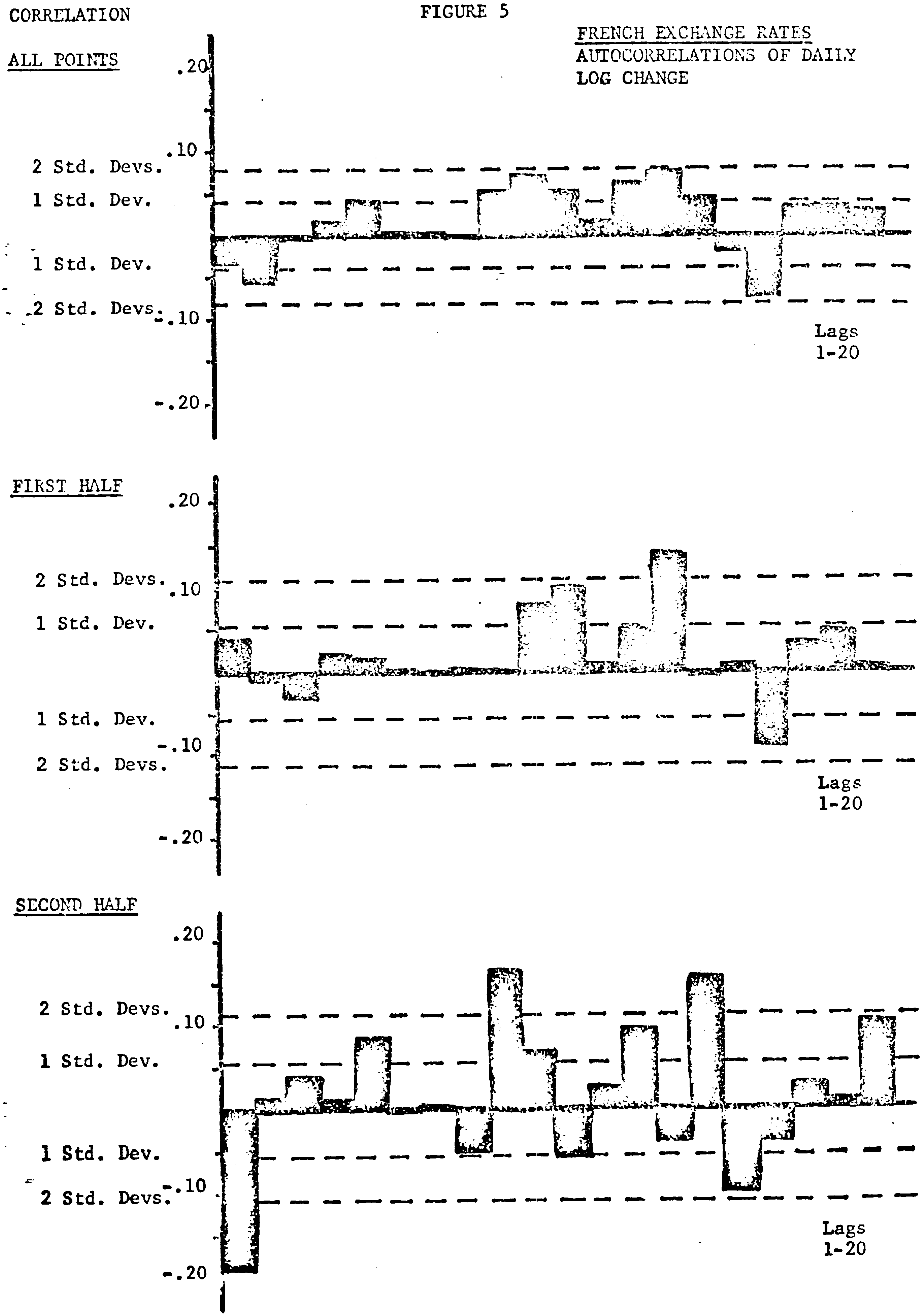

FIGURE 6

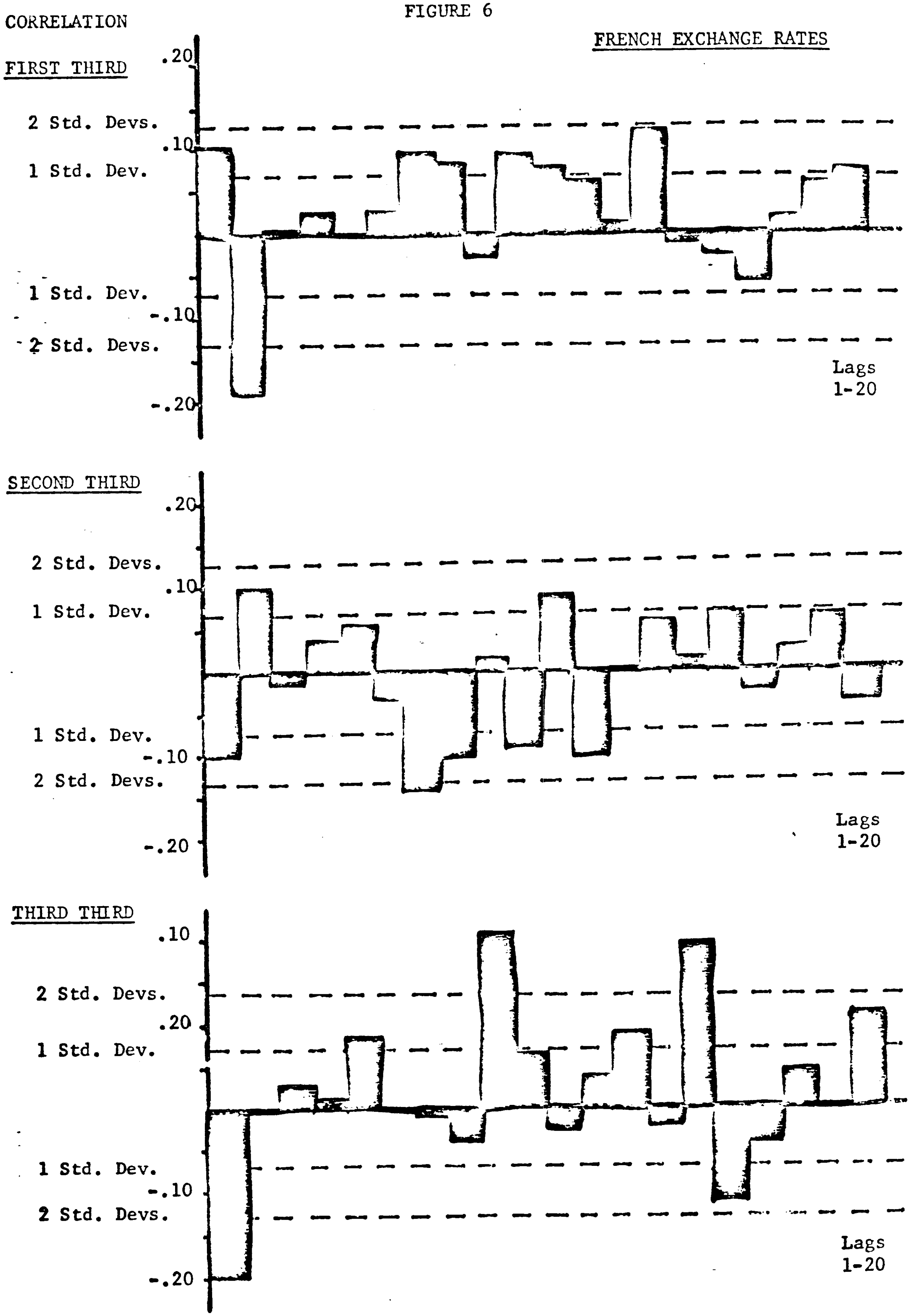
CORRELATION
FRENCH EXCHANGE RATES
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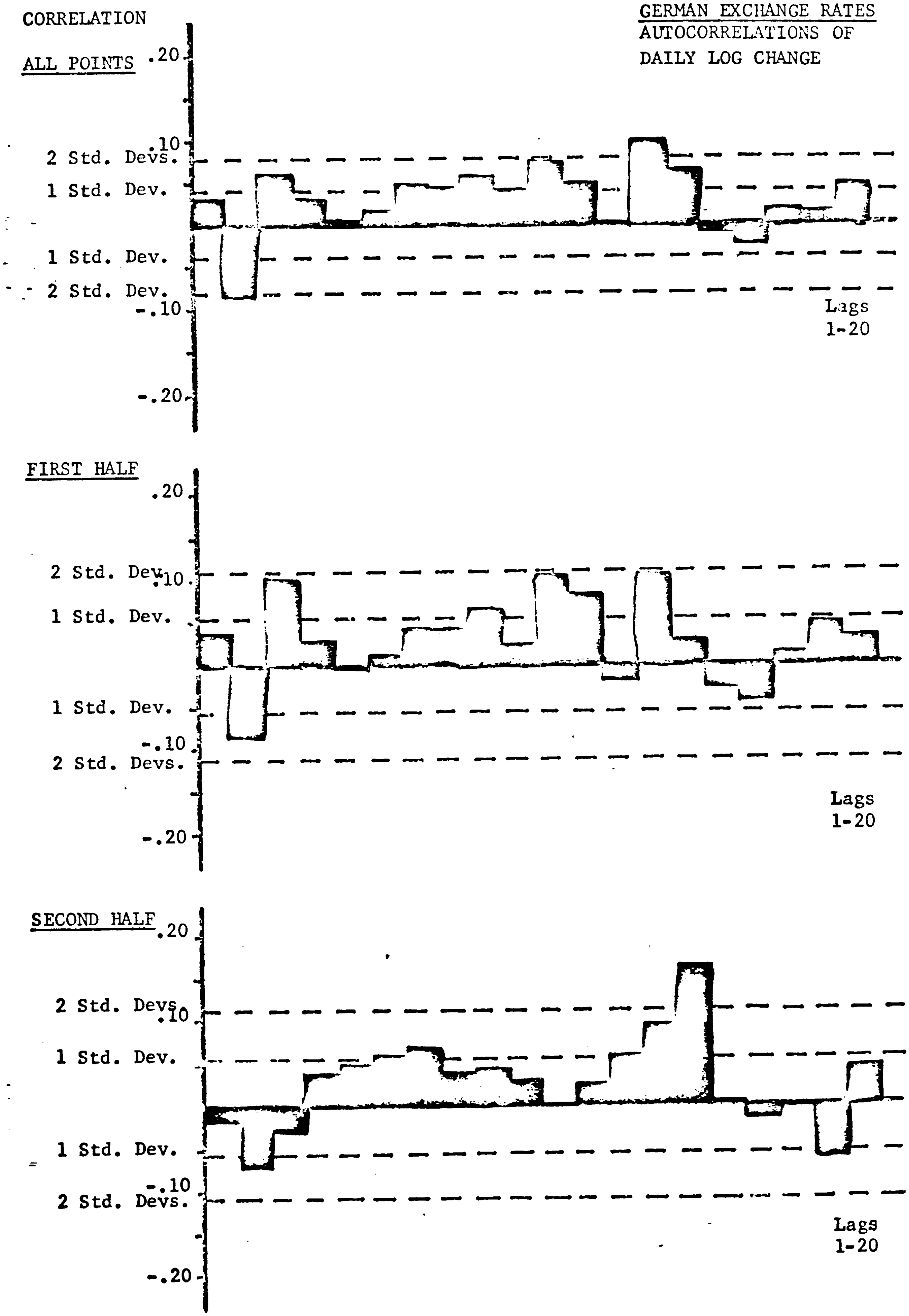
FIGURE 7



CORRELATION
GERMAN EXCHANGE RATES
AUTOCORRELATIONS OF
DAILY LOG CHANGE
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Lags
1-20

FIGURE 8

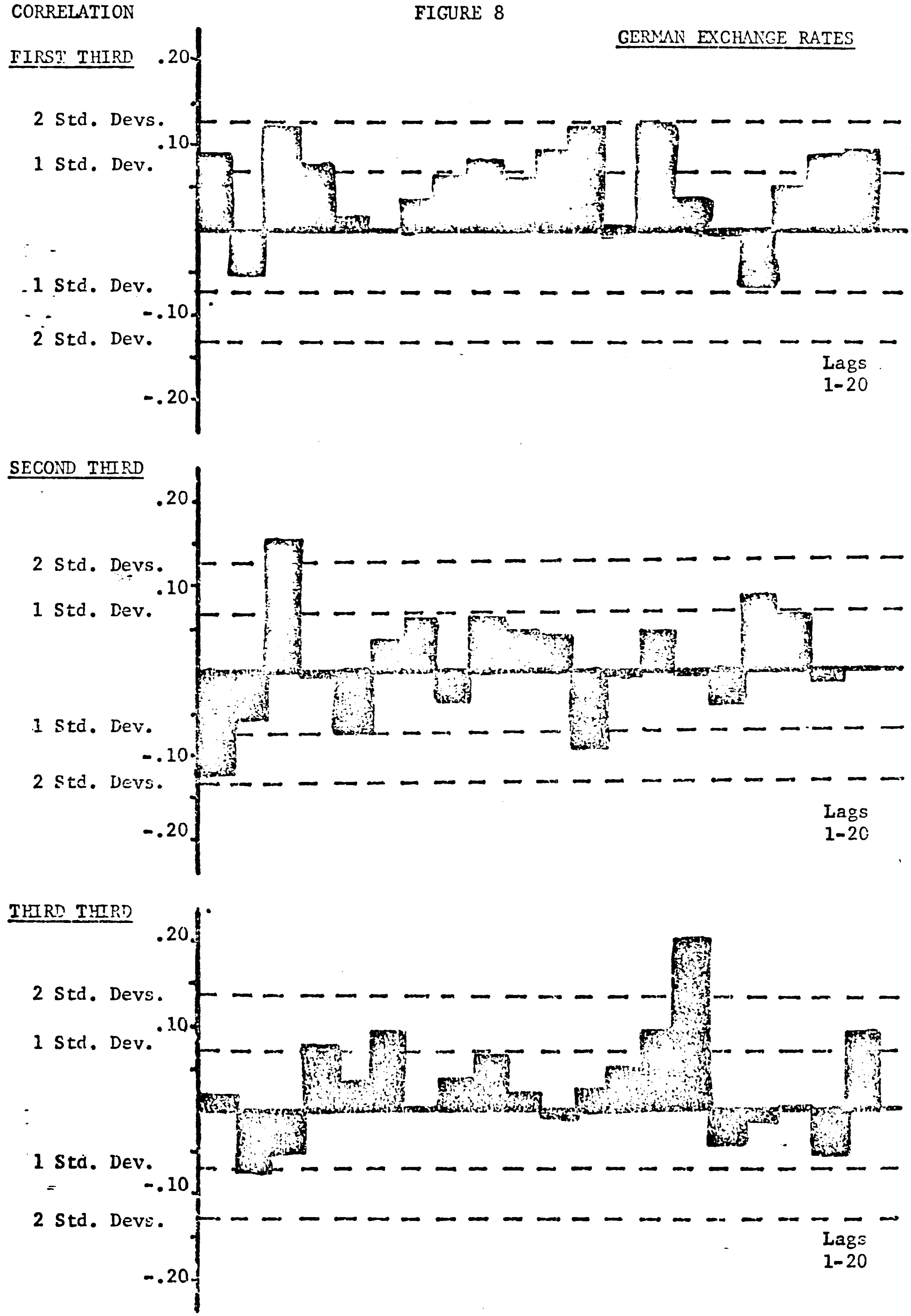

CORRELATION
GERMAN EXCHANGE RATES
FIRST THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Dev.
Lags
1-20
-.20
SECOND THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags
1-20
THIRD THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20
-.20

FIGURE 9

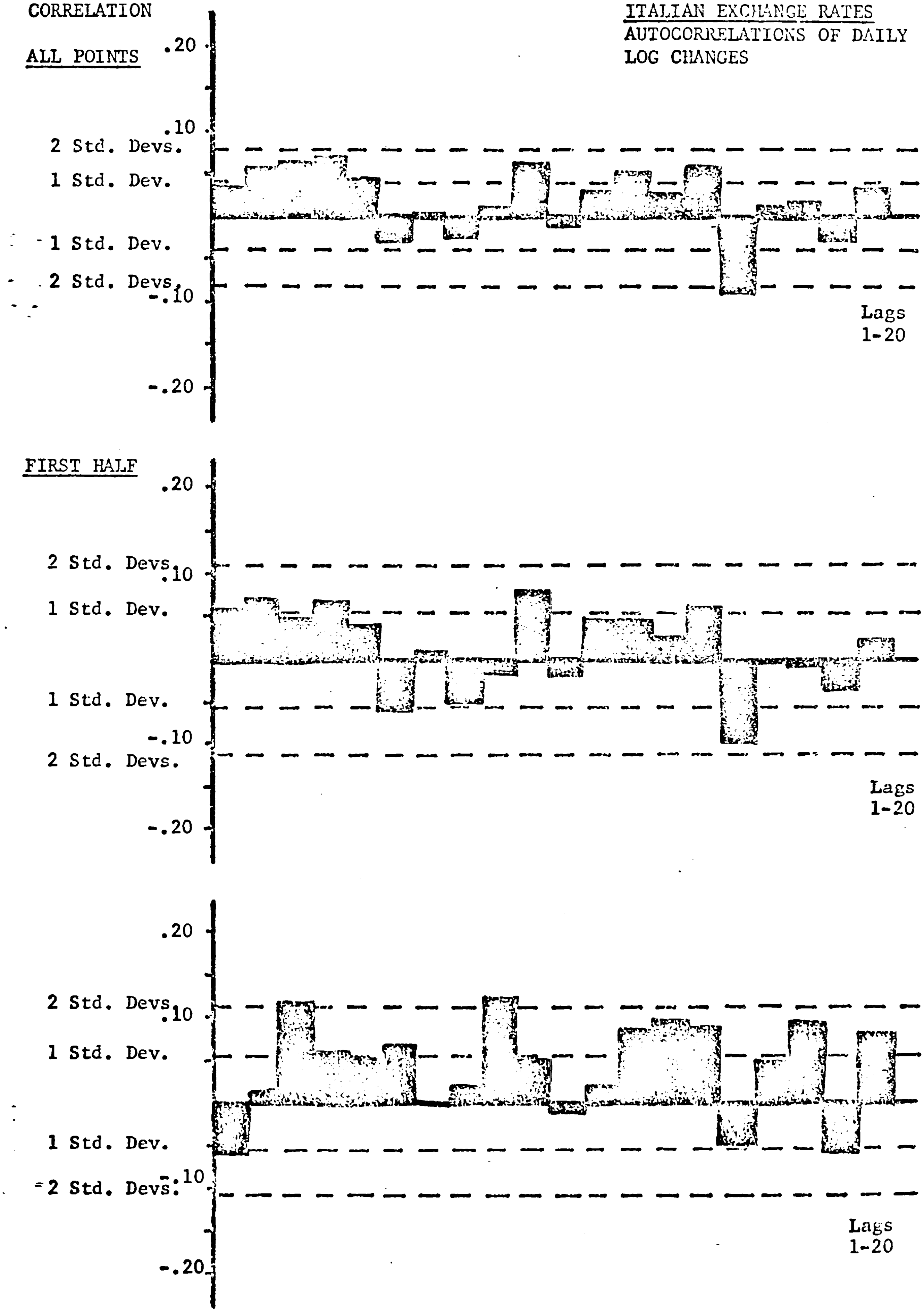

CORRELATION
ITALIAN EXCHANGE RATES
AUTOCORRELATIONS OF DAILY LOG CHANGES
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
1 Std. Dev.
2 Std. Devs
-.10
Lags 1-20
-.20
FIRST HALF
.20
2 Std. Devs
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags 1-20
-.20
.20
2 Std. Devs
.10
1 Std. Dev.
1 Std. Dev.
2 Std. Devs.
-.10
Lags 1-20
-.20

FIGURE 10

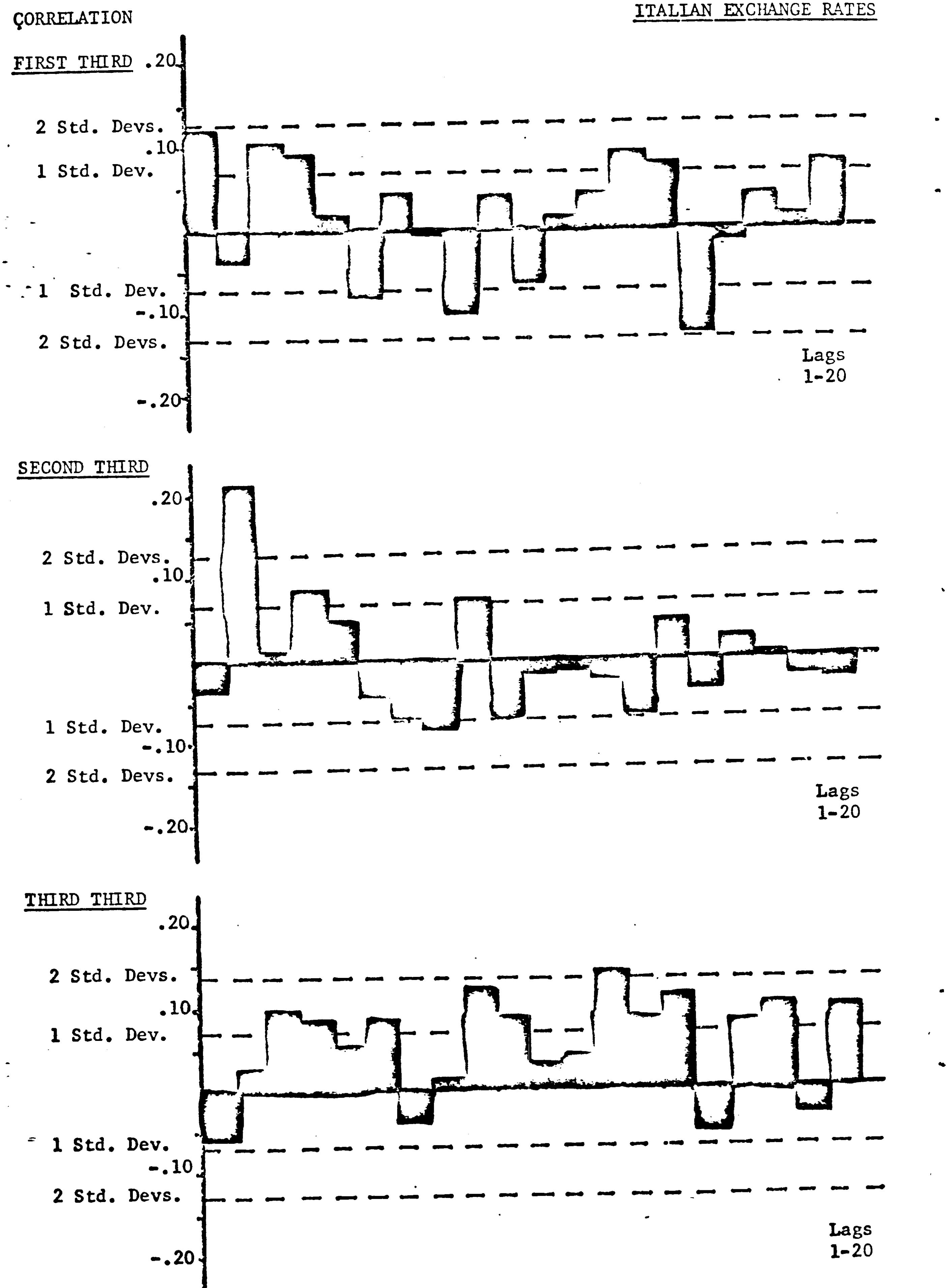
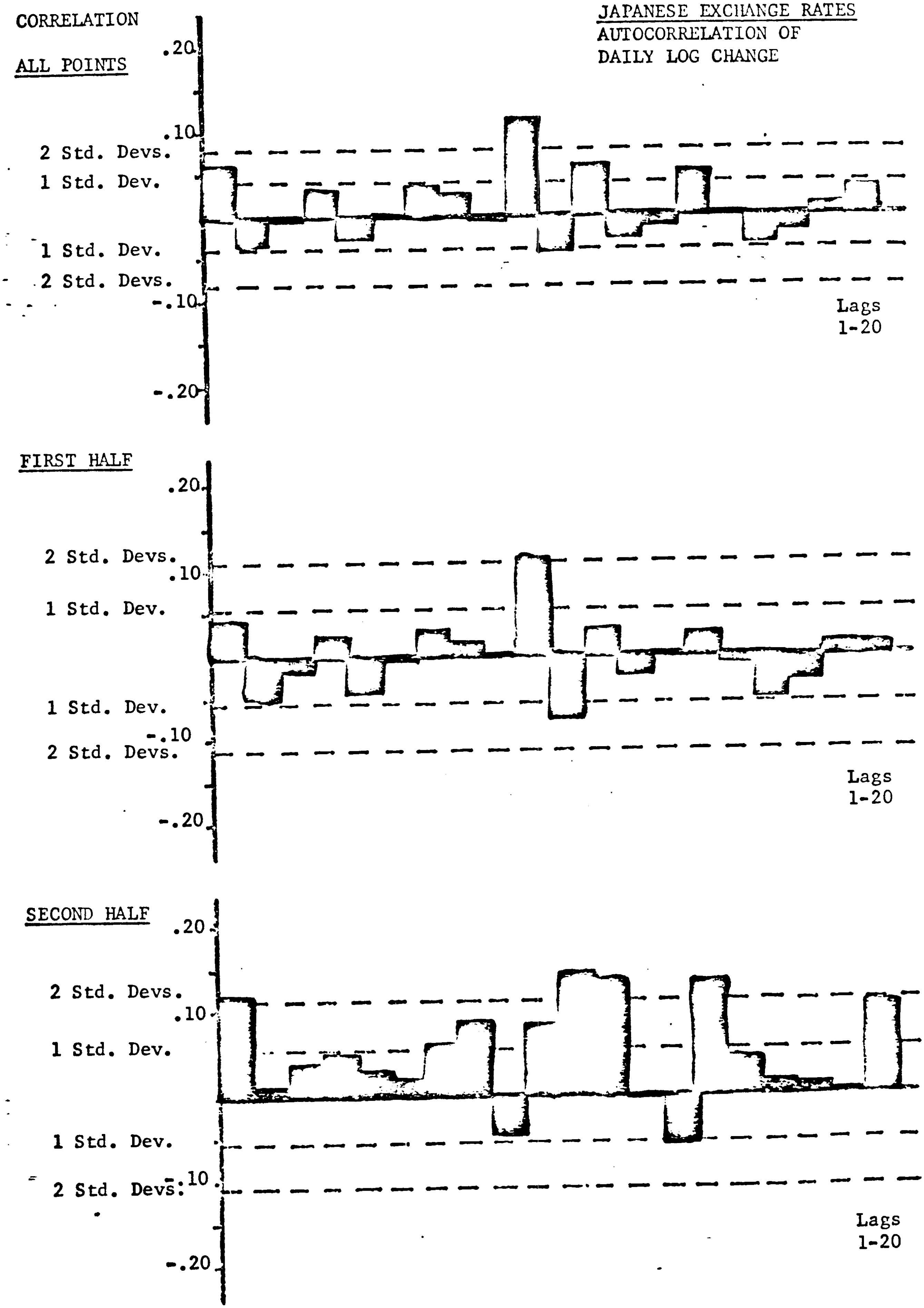
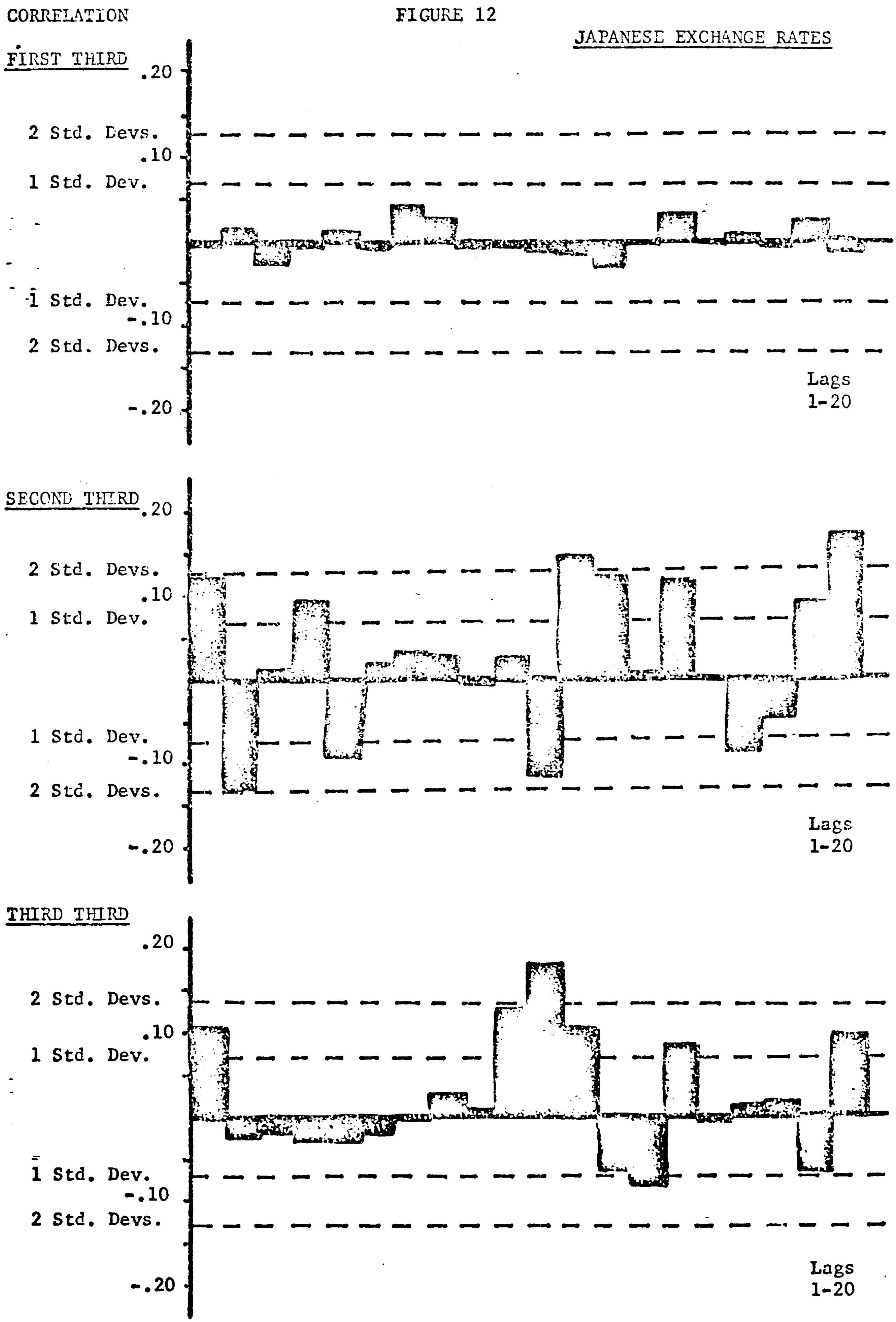

CORRELATION
ITALIAN EXCHANGE RATES
FIRST THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags 1-20
SECOND THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags 1-20
THIRD THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags 1-20

FIGURE 11



CORRELATION
JAPANESE EXCHANGE RATES
AUTOCORRELATION OF
DAILY LOG CHANGE
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
-1 Std. Dev.
-2 Std. Devs.
-.10
-.20
Lags
1-20
FIRST HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags
1-20
SECOND HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags
1-20

FIGURE 12



CORRELATION
JAPANESE EXCHANGE RATES
FIRST THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags 1-20
SECOND THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags 1-20
THIRD THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags 1-20

FIGURE 13

NETHERLANDS' EXCHANGE RATES
AUTOCORRELATIONS OF
DAILY LOG CHANGE

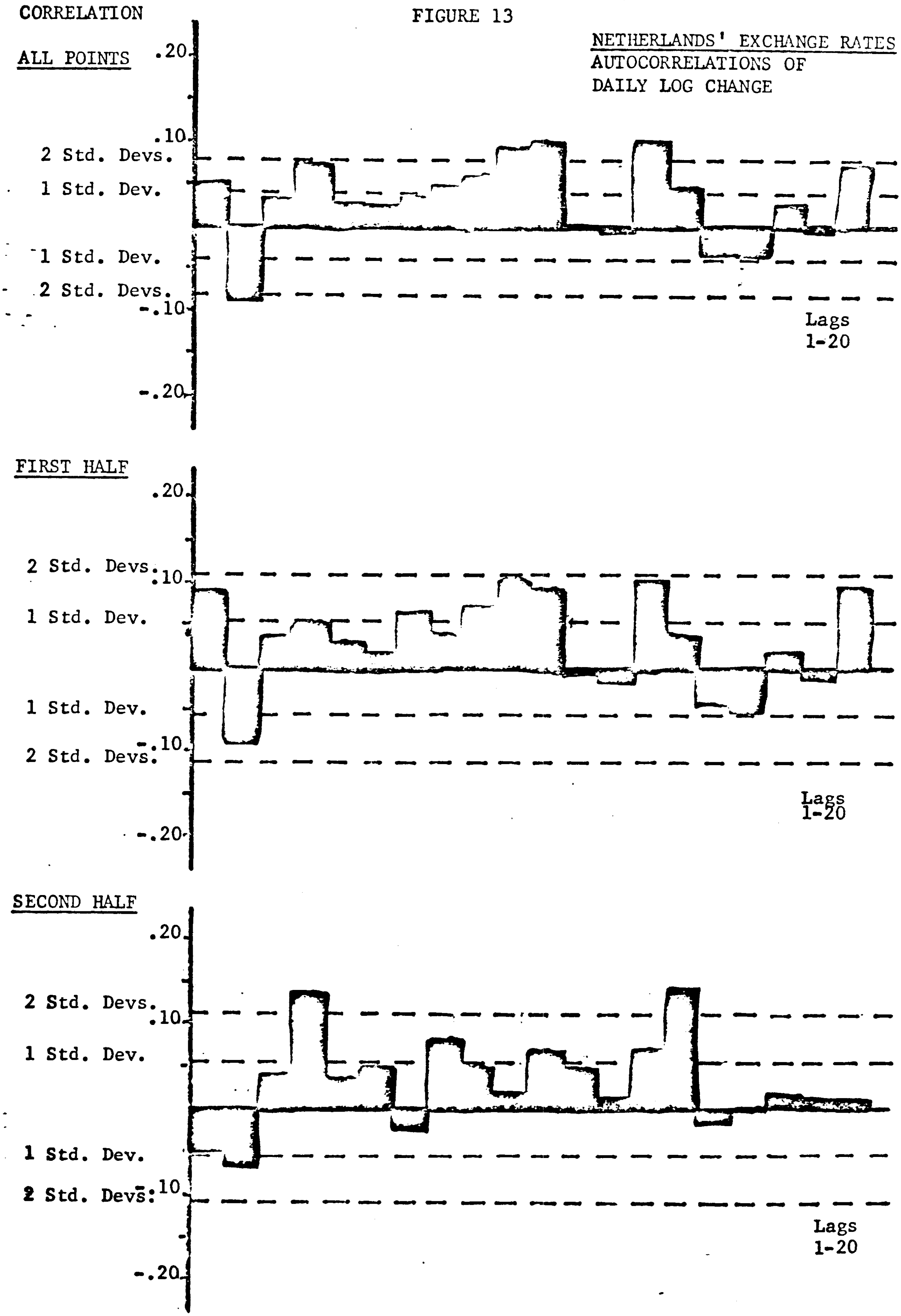


FIGURE 14

NETHERLANDS' EXCHANGE RATES

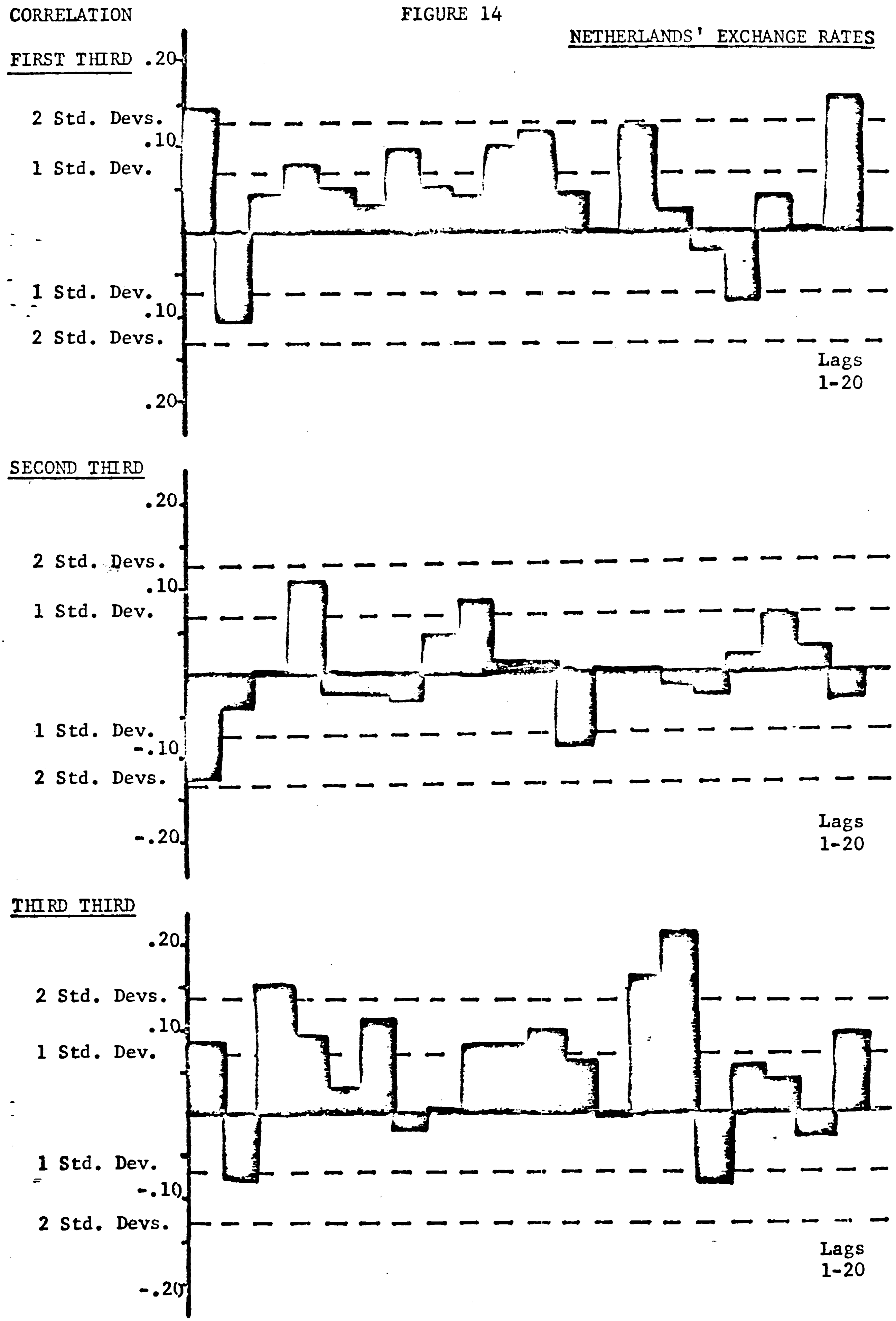
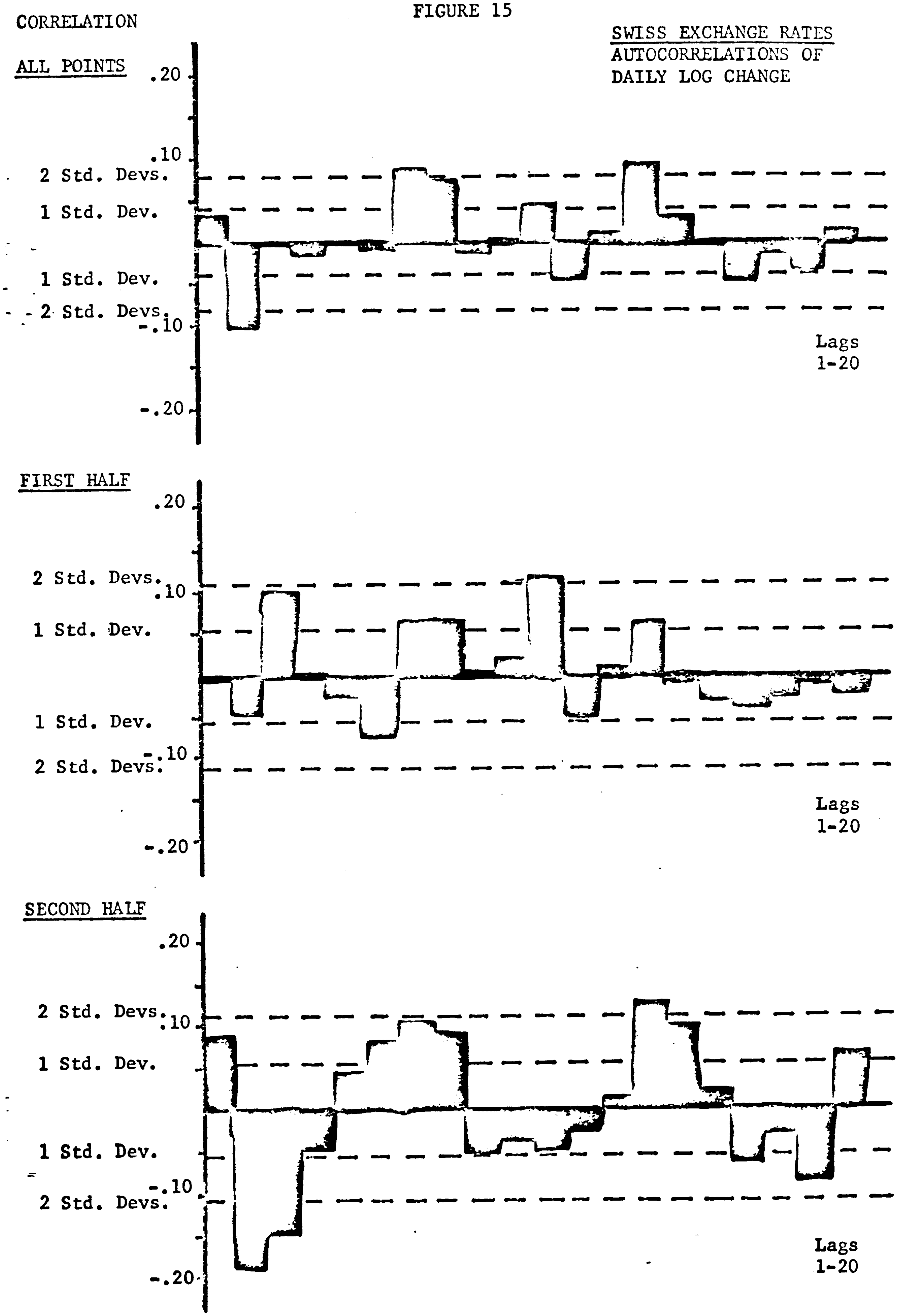


FIGURE 15



CORRELATION
SWISS EXCHANGE RATES
AUTOCORRELATIONS OF
DAILY LOG CHANGE
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
1 Std. Dev.
2 Std. Devs.
-.10
-.20
Lags
1-20
FIRST HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags
1-20
SECOND HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
-.20
Lags
1-20

CORRELATION

FIGURE 16

SWISS EXCHANGE RATES

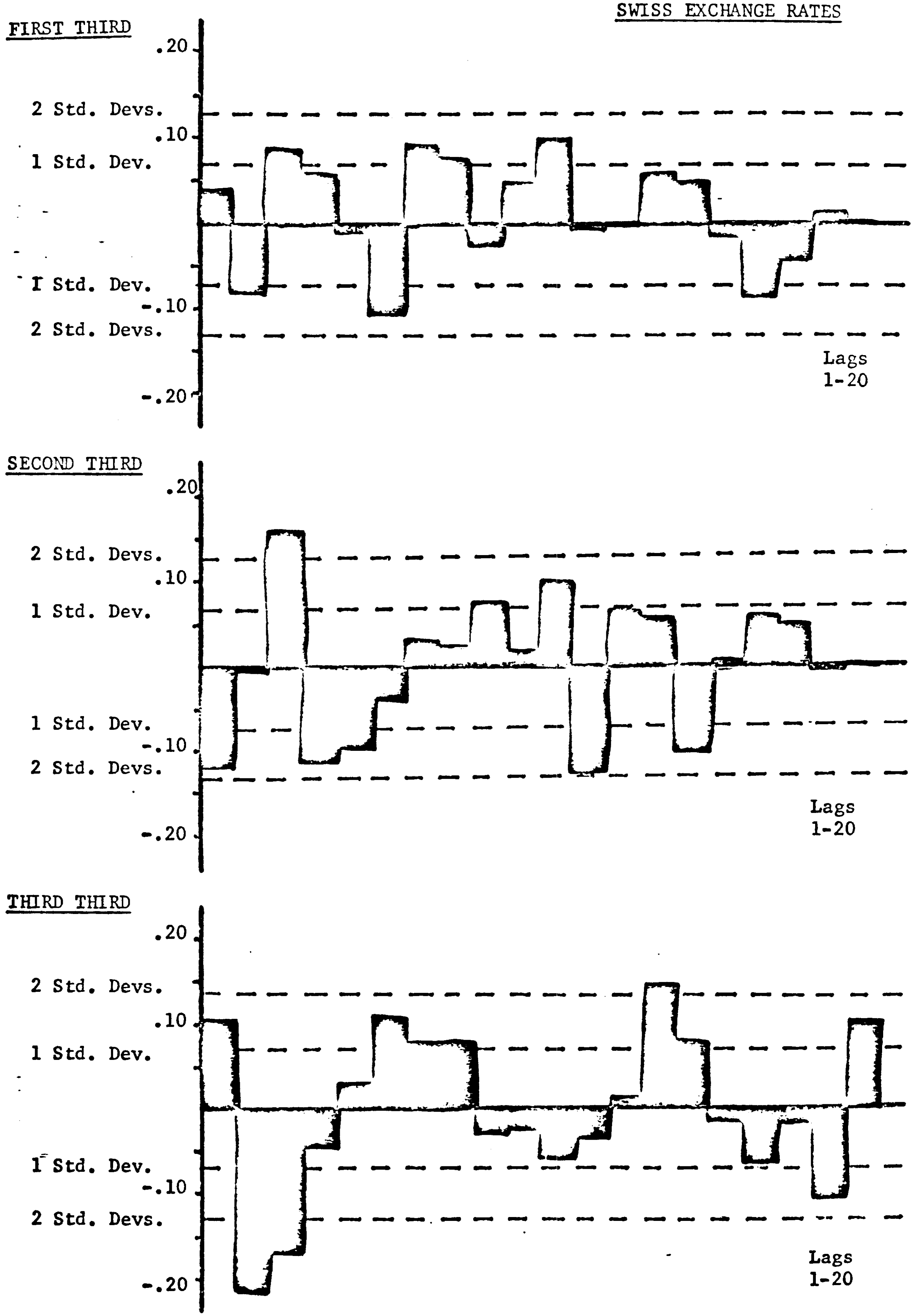
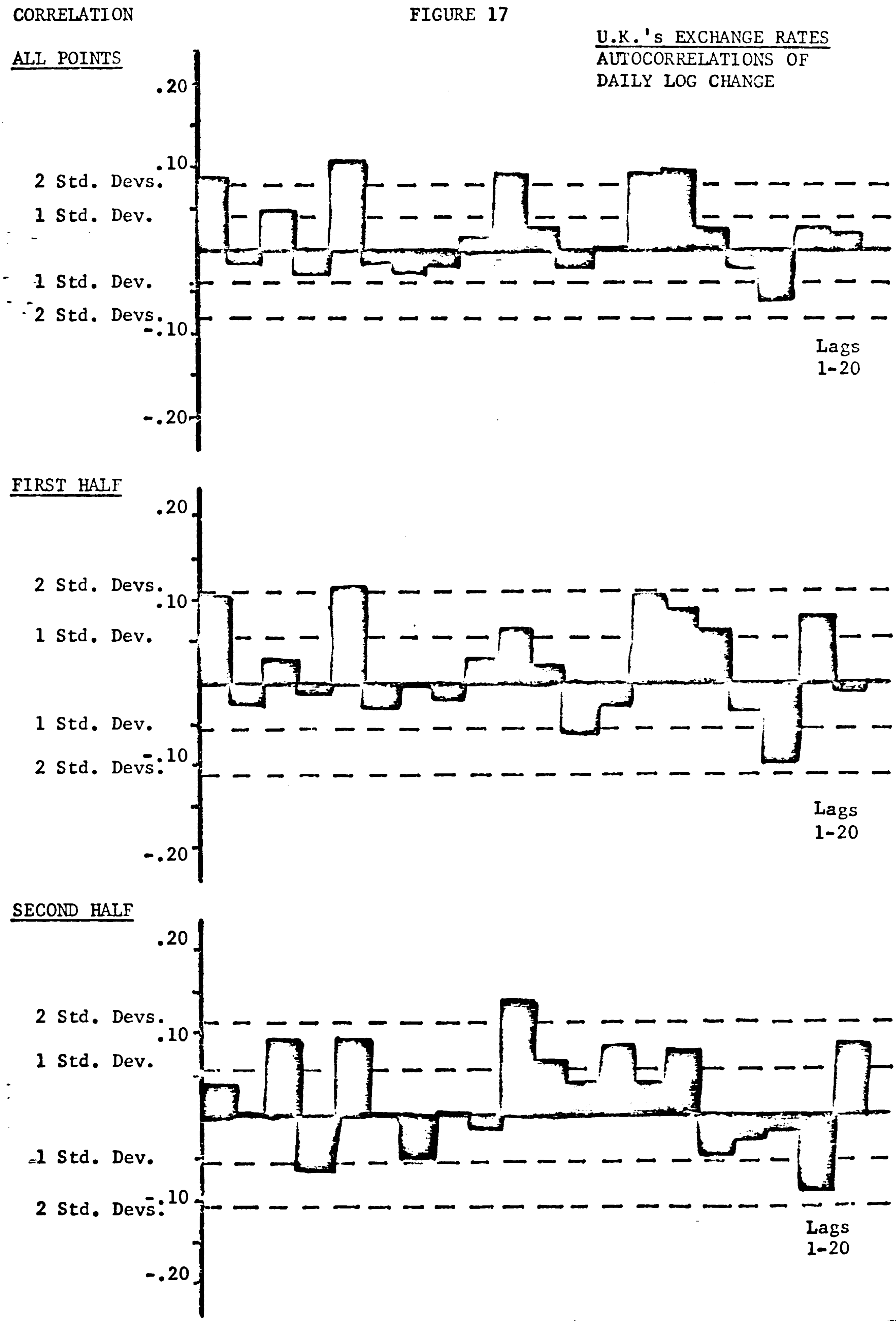


FIGURE 17

U.K.'s EXCHANGE RATES
AUTOCORRELATIONS OF
DAILY LOG CHANGE



CORRELATION

FIGURE 18

U.K.'s EXCHANGE RATES

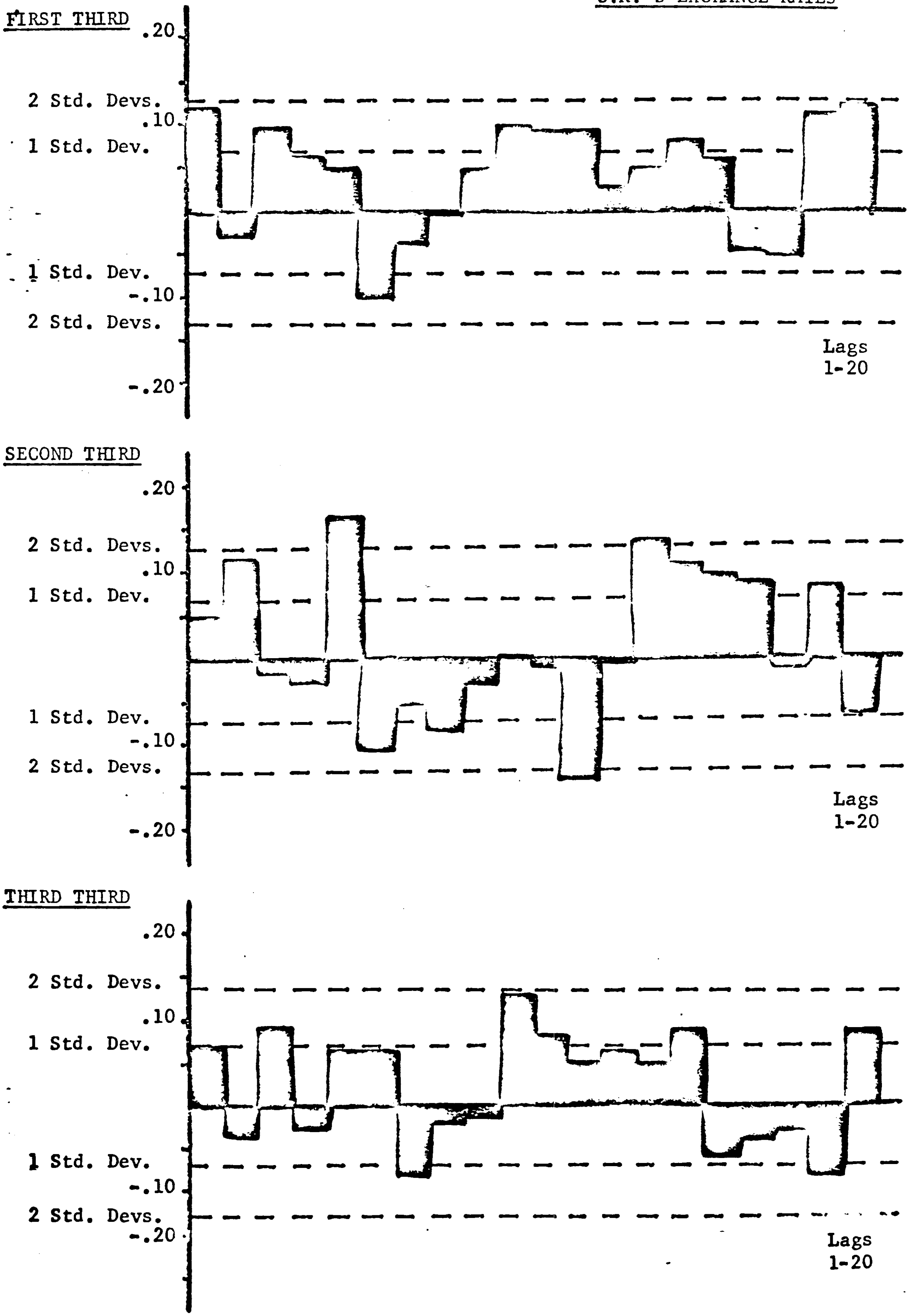


FIGURE 19

RANDOM WALK #1

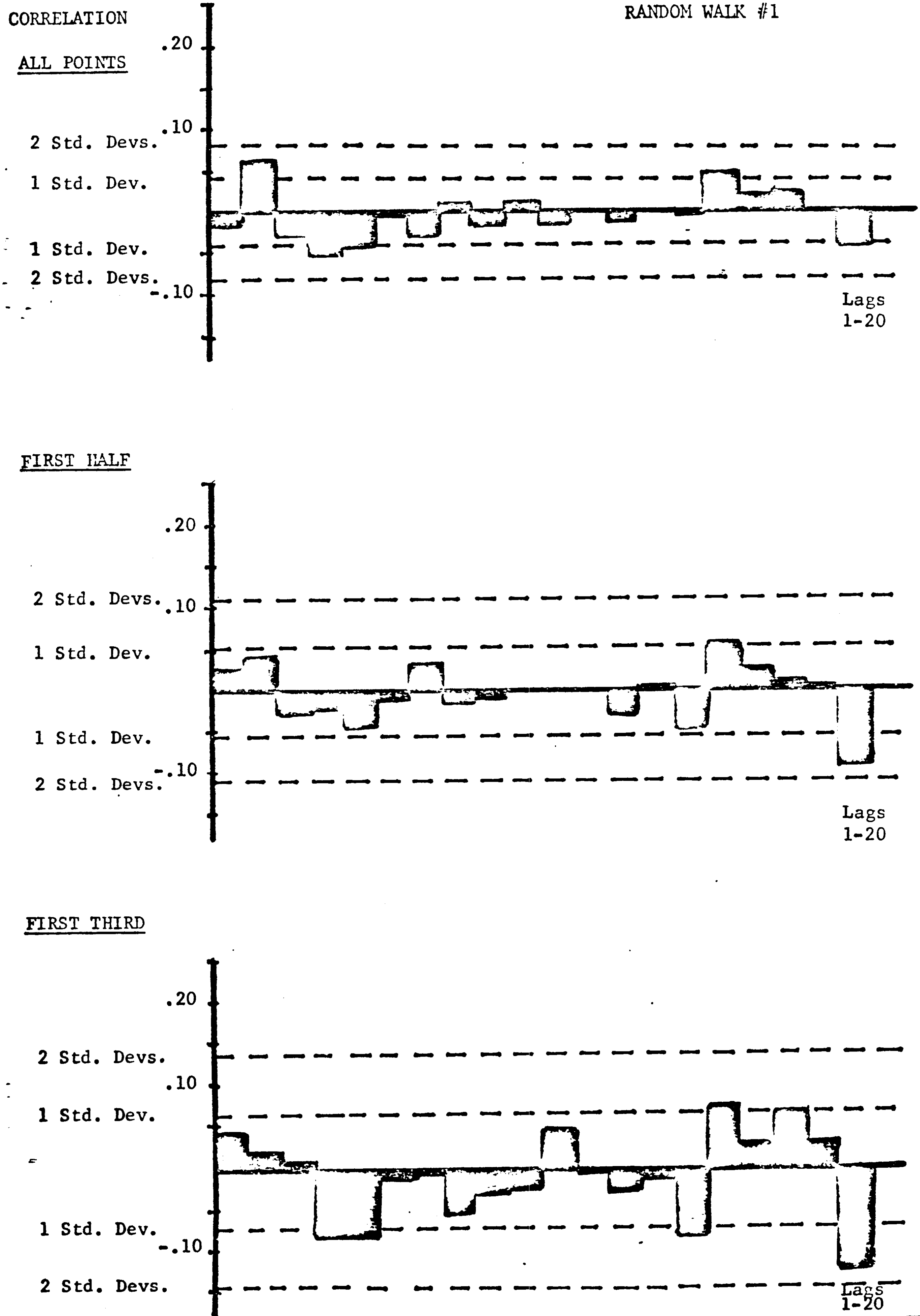
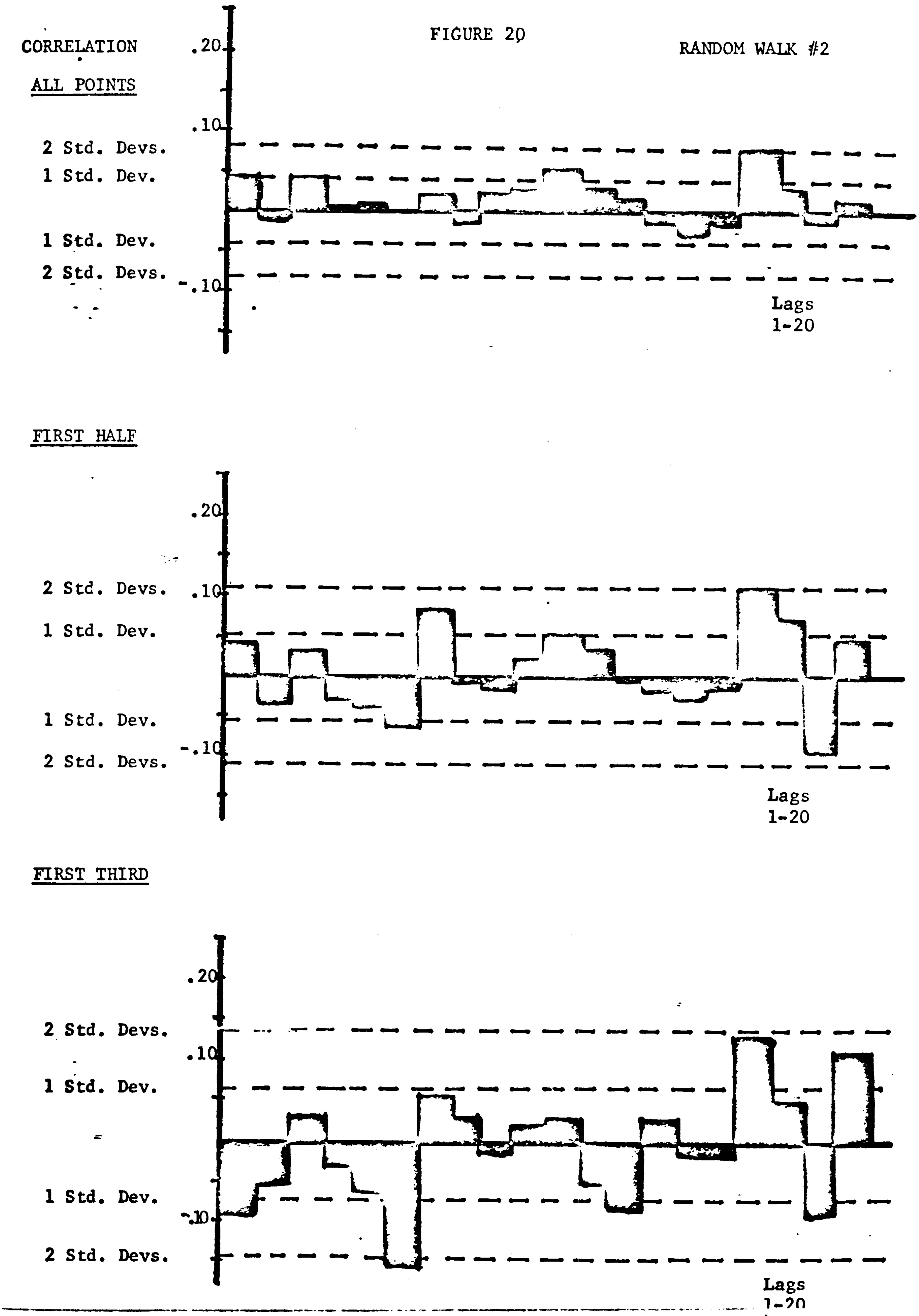


FIGURE 20



CORRELATION
RANDOM WALK #2
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
1 Std. Dev.
2 Std. Devs.
-.10
Lags
1-20
FIRST HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20
FIRST THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20

FIGURE 21

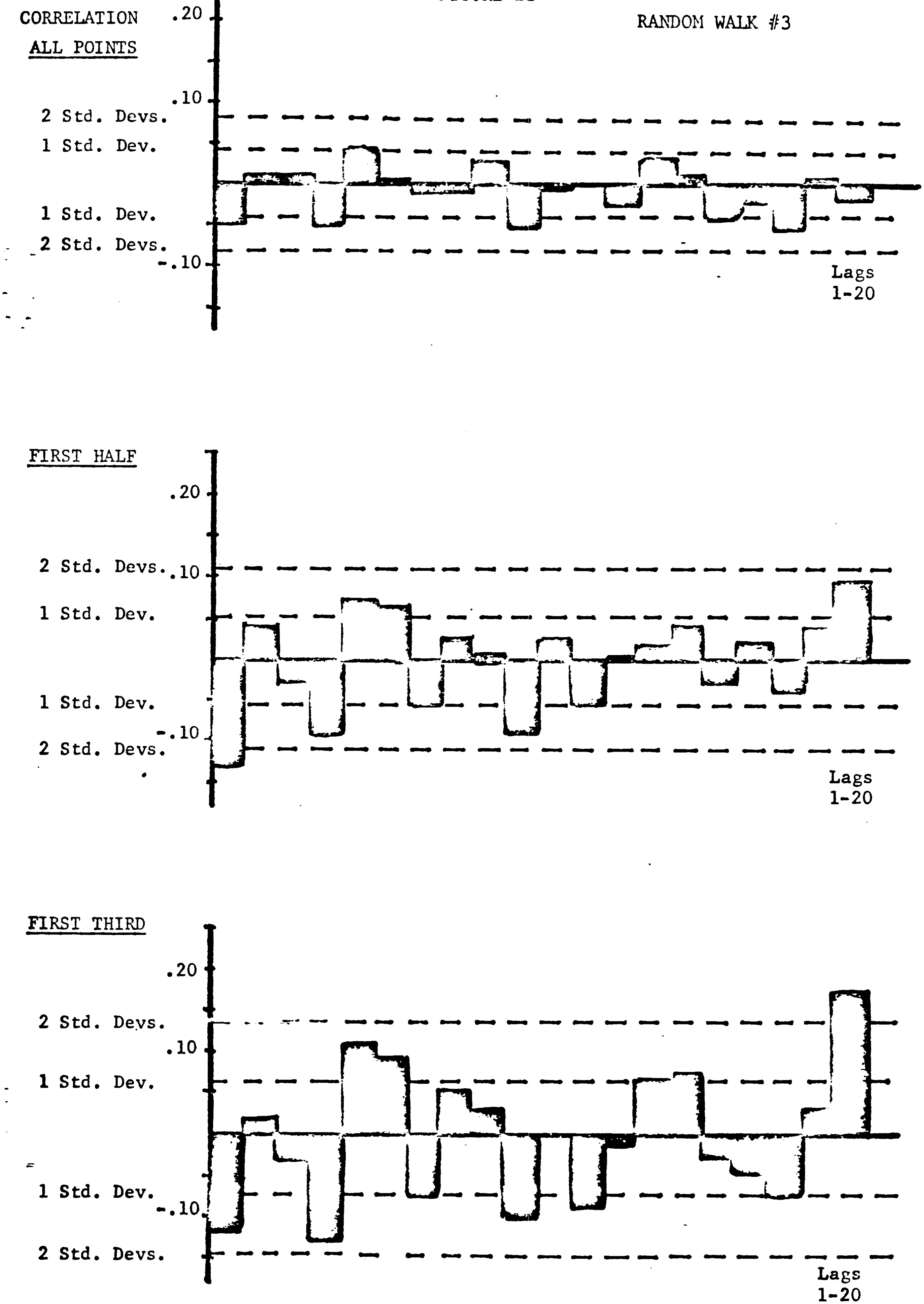
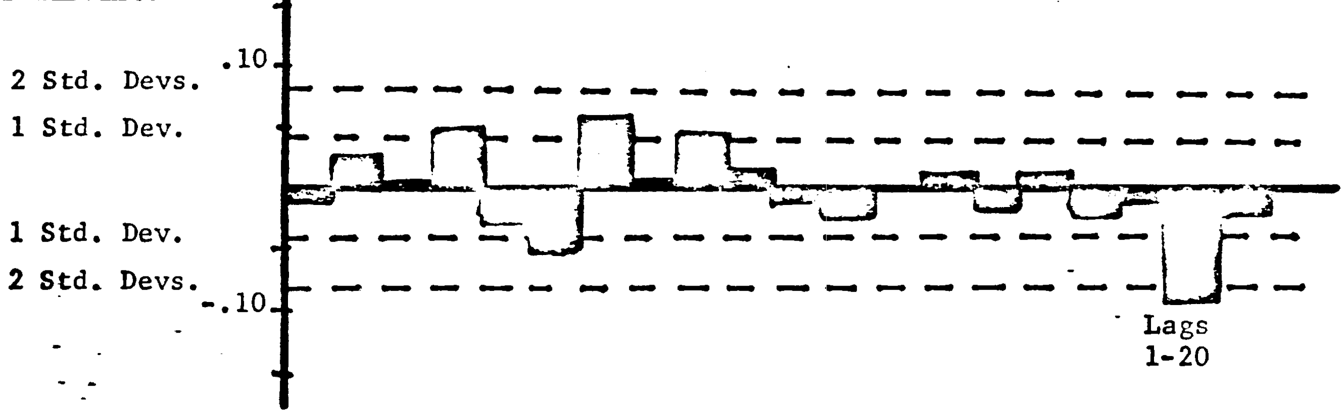

RANDOM WALK #3
CORRELATION
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
1 Std. Dev.
2 Std. Devs.
-.10
Lags
1-20
FIRST HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20
FIRST THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20

FIGURE 22

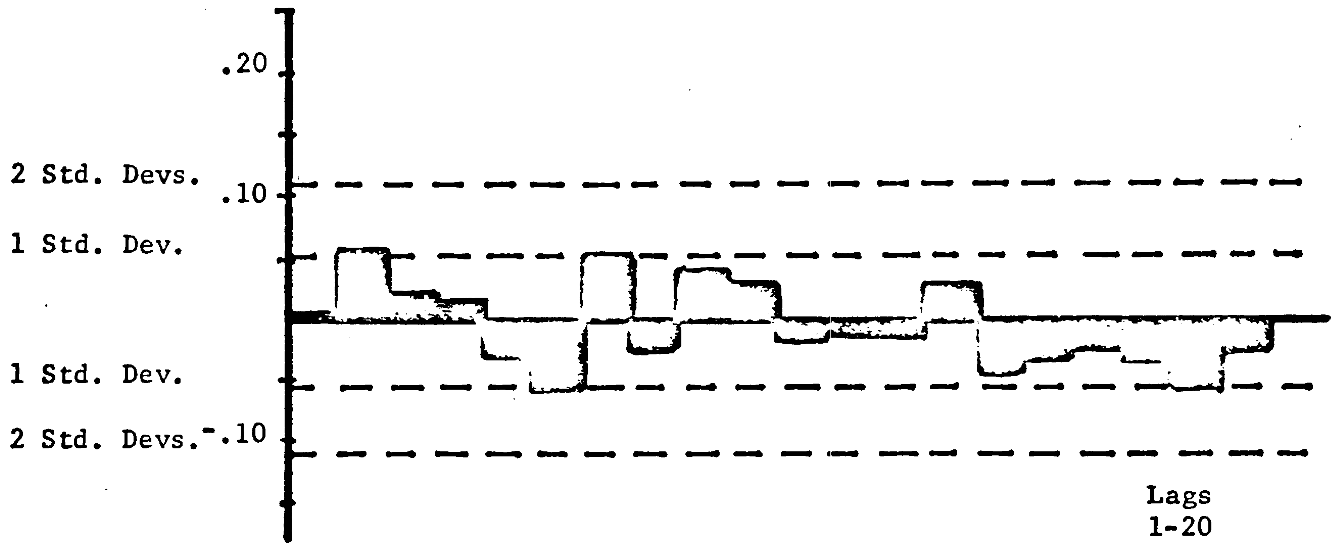
RANDOM WALK #4

CORRELATION

ALL POINTS



FIRST HALF



FIRST THIRD

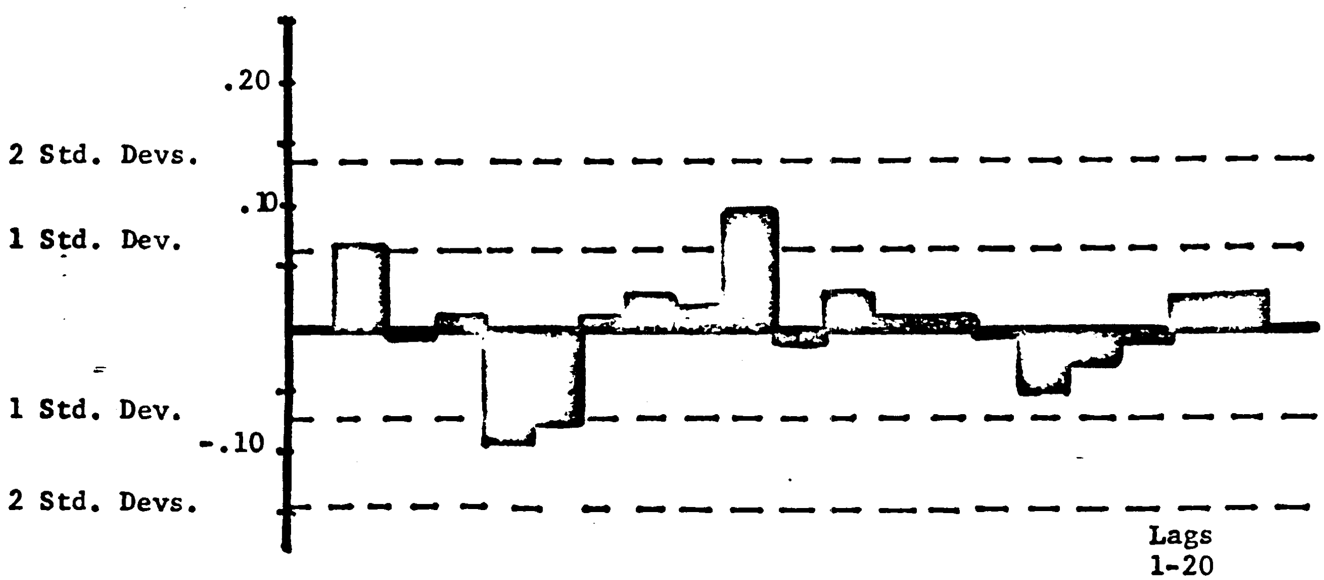
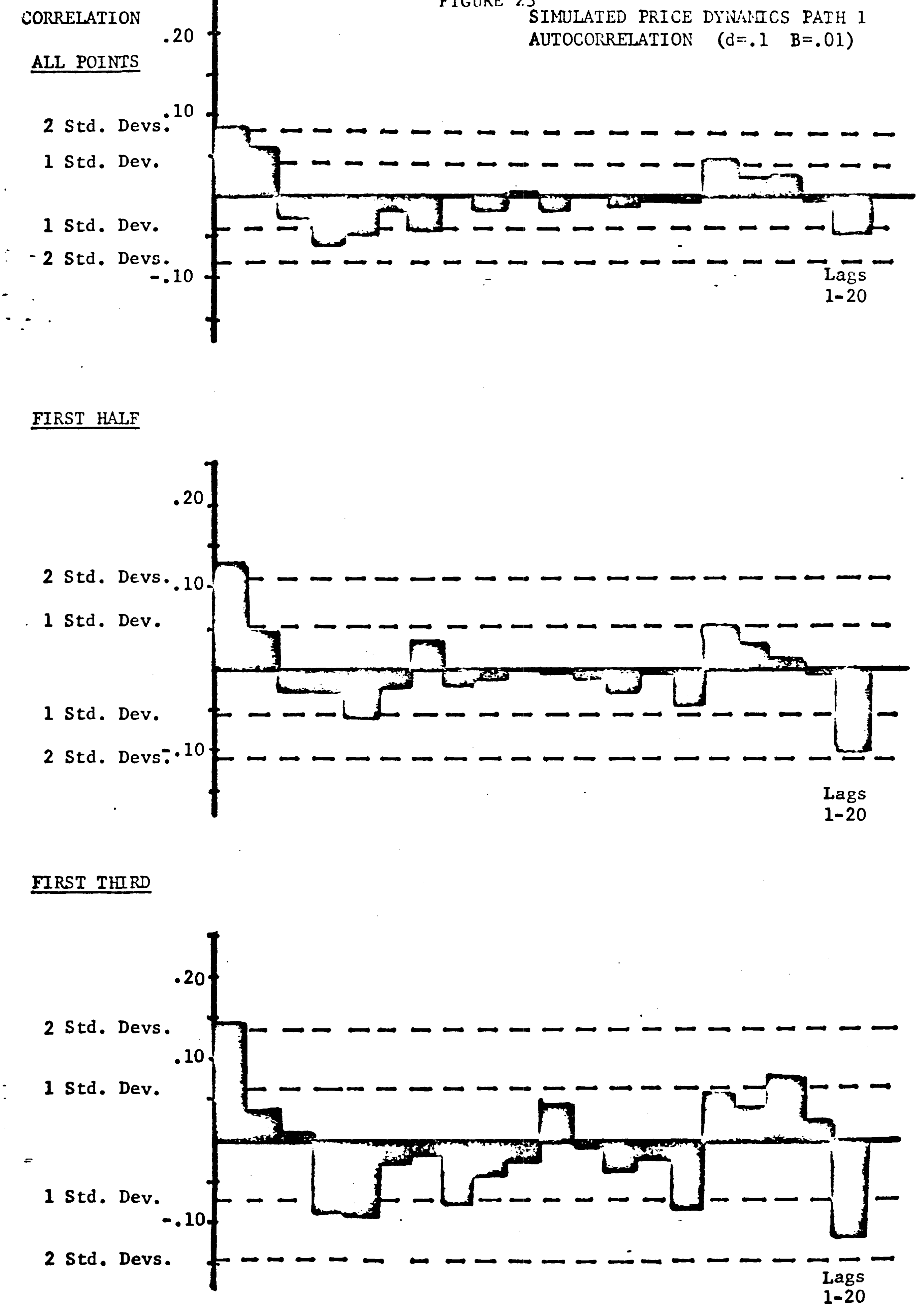


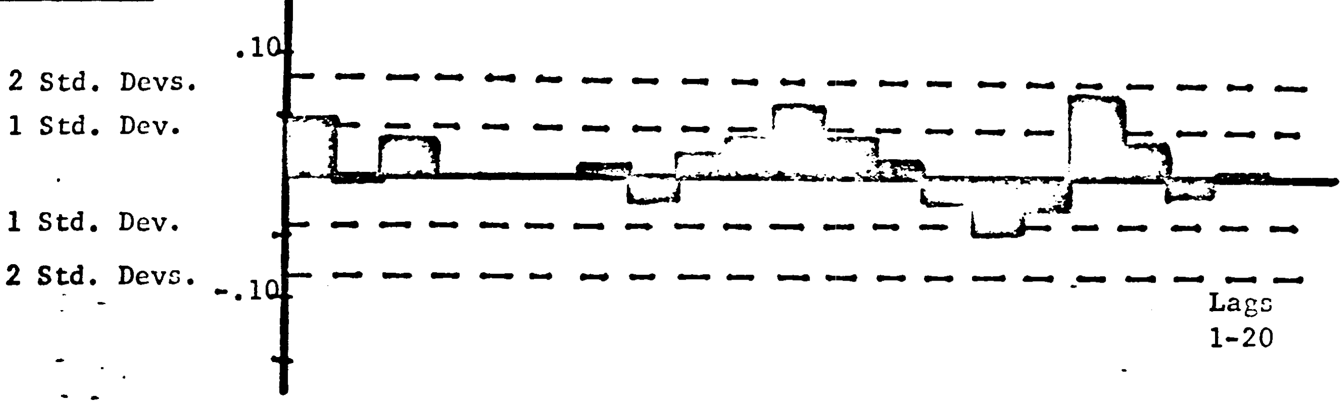
FIGURE 23

SIMULATED PRICE DYNAMICS PATH 1
AUTOCORRELATION (d=.1 B=.01)

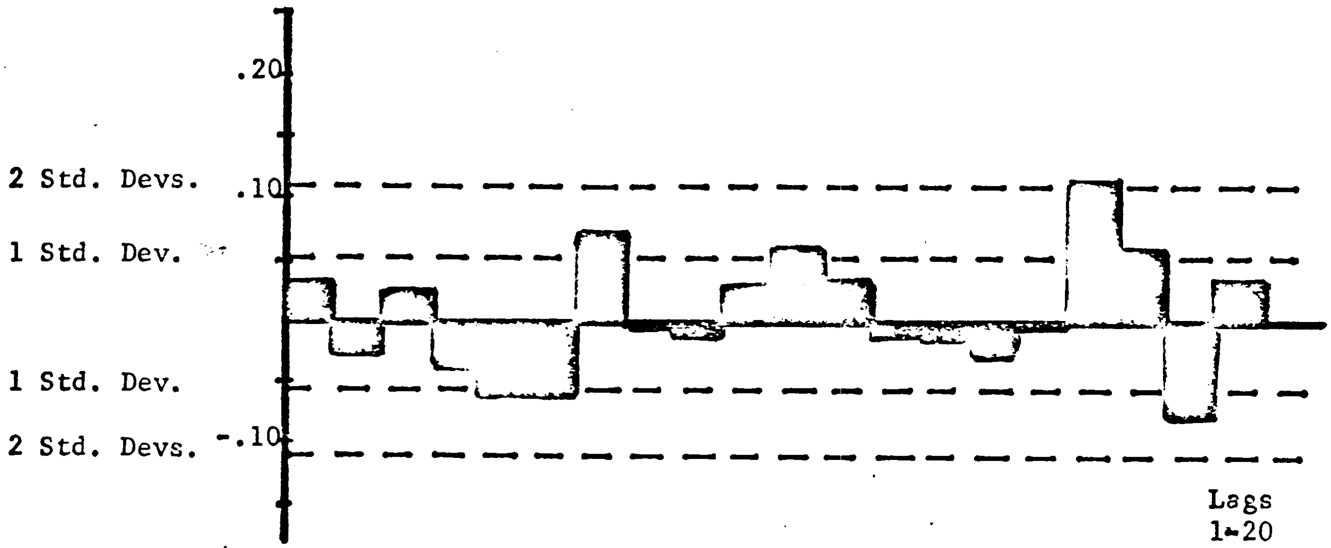


SIMULATED PRICE DYNAMICS PATH 2
AUTOCORRELATION (d=.1 B=.01)

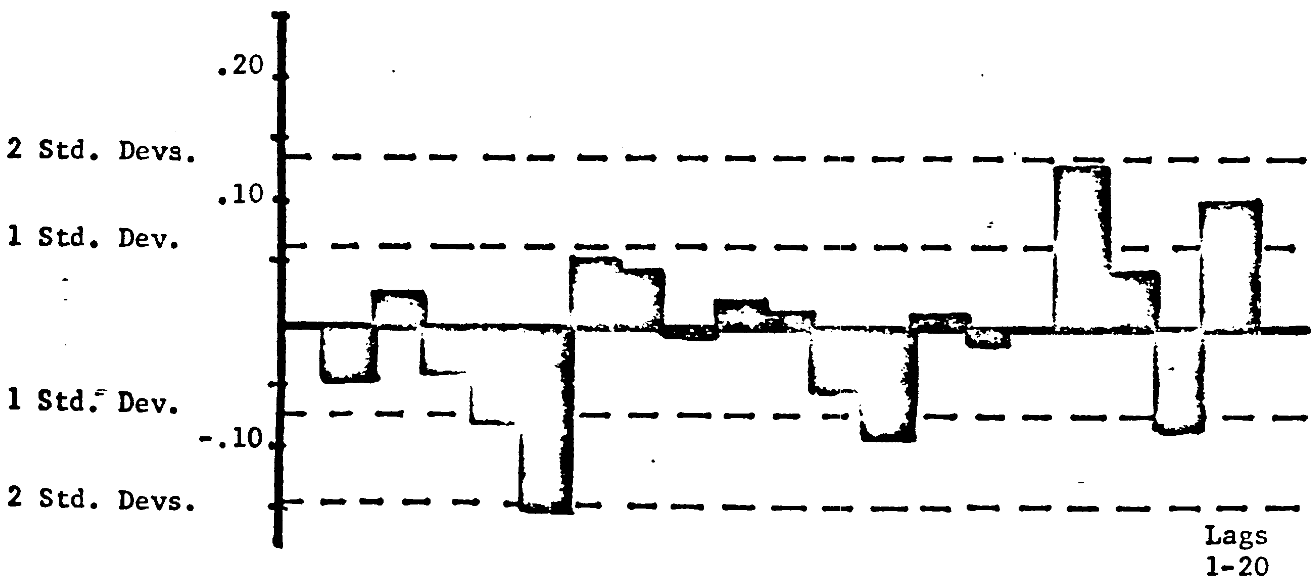
ALL POINTS



FIRST HALF



FIRST THIRD



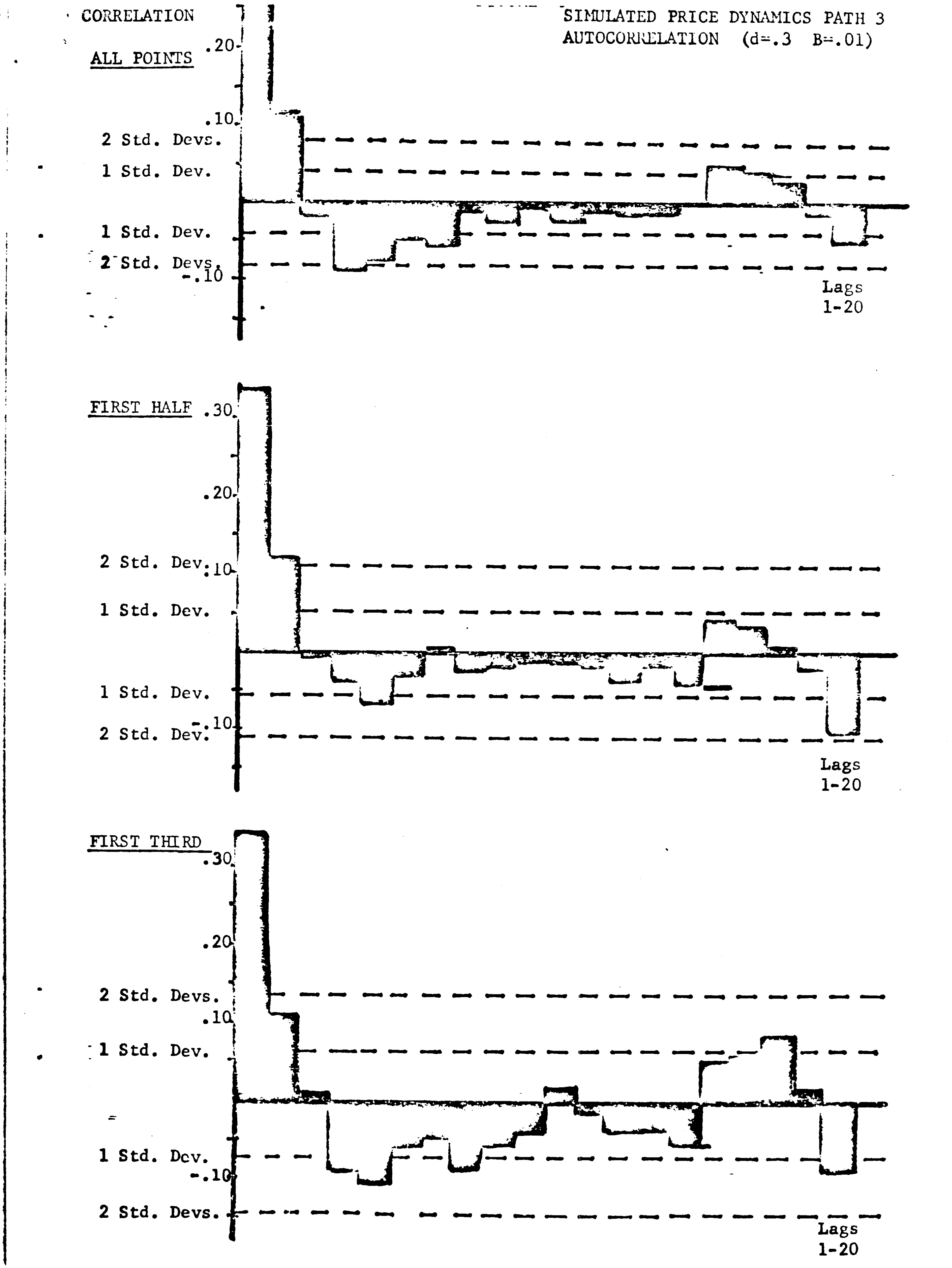

SIMULATED PRICE DYNAMICS PATH 3
AUTOCORRELATION (d=.3 B=.01)
CORRELATION
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
1 Std. Dev.
2 Std. Devs.
-.10
Lags 1-20
FIRST HALF
.30
.20
2 Std. Dev.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Dev.
Lags 1-20
FIRST THIRD
.30
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags 1-20

FIGURE 26

SIMULATED PRICE DYNAMICS PATH 4
AUTOCORRELATION (d=.1 B=.01)

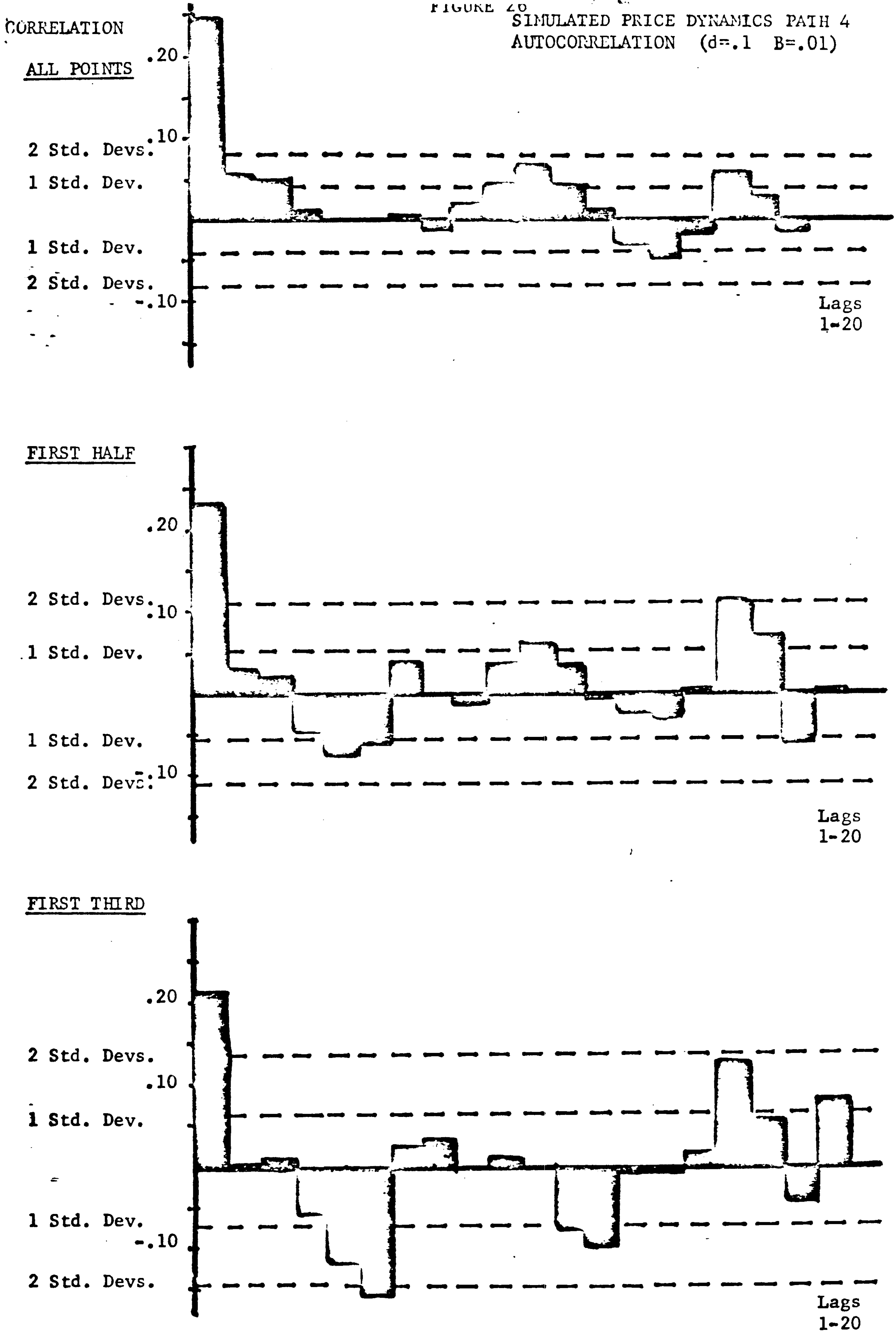


FIGURE 27

SIMULATED PRICE DYNAMICS PATH 5
AUTOCORRELATION (=.1 B=.05)

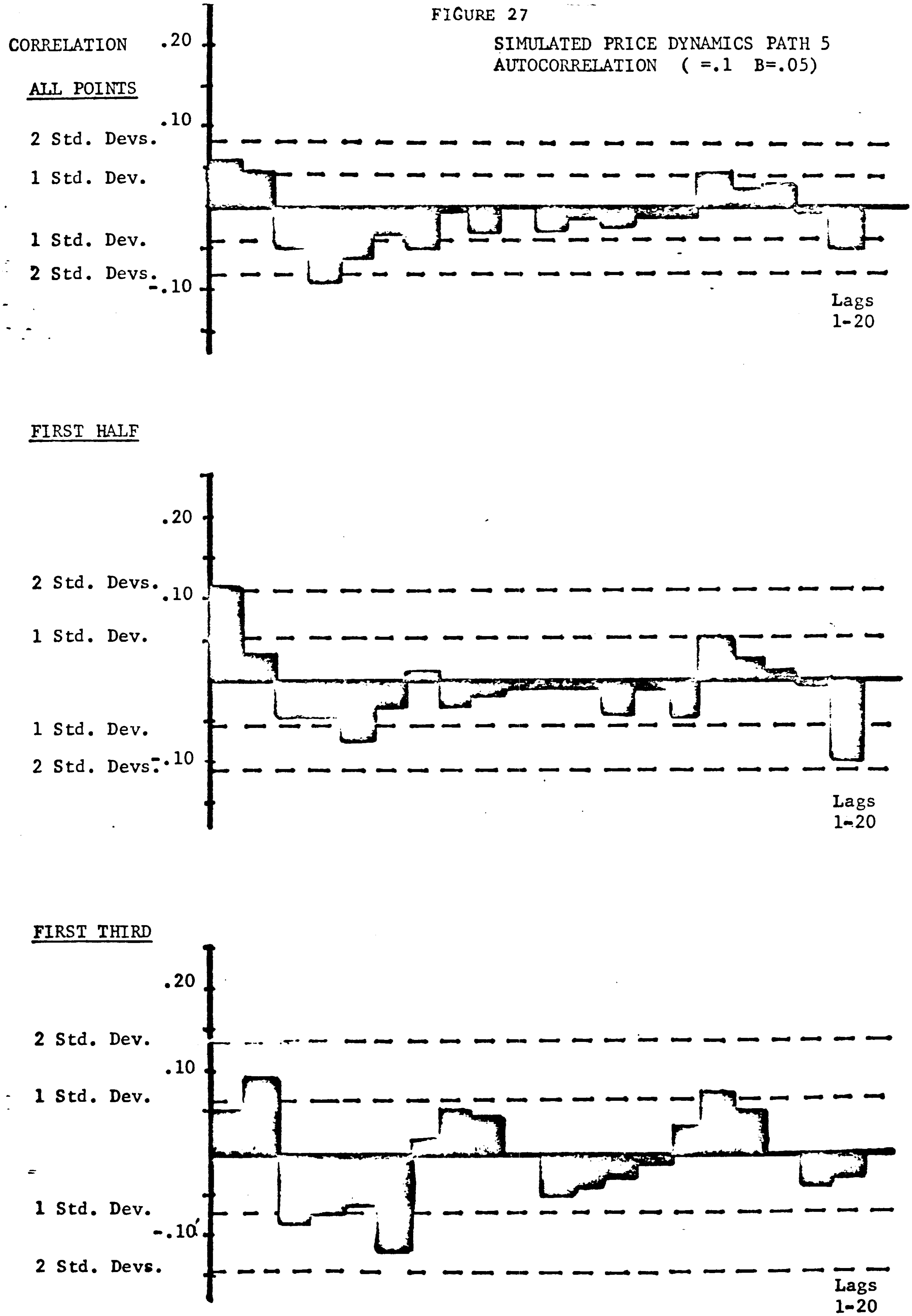
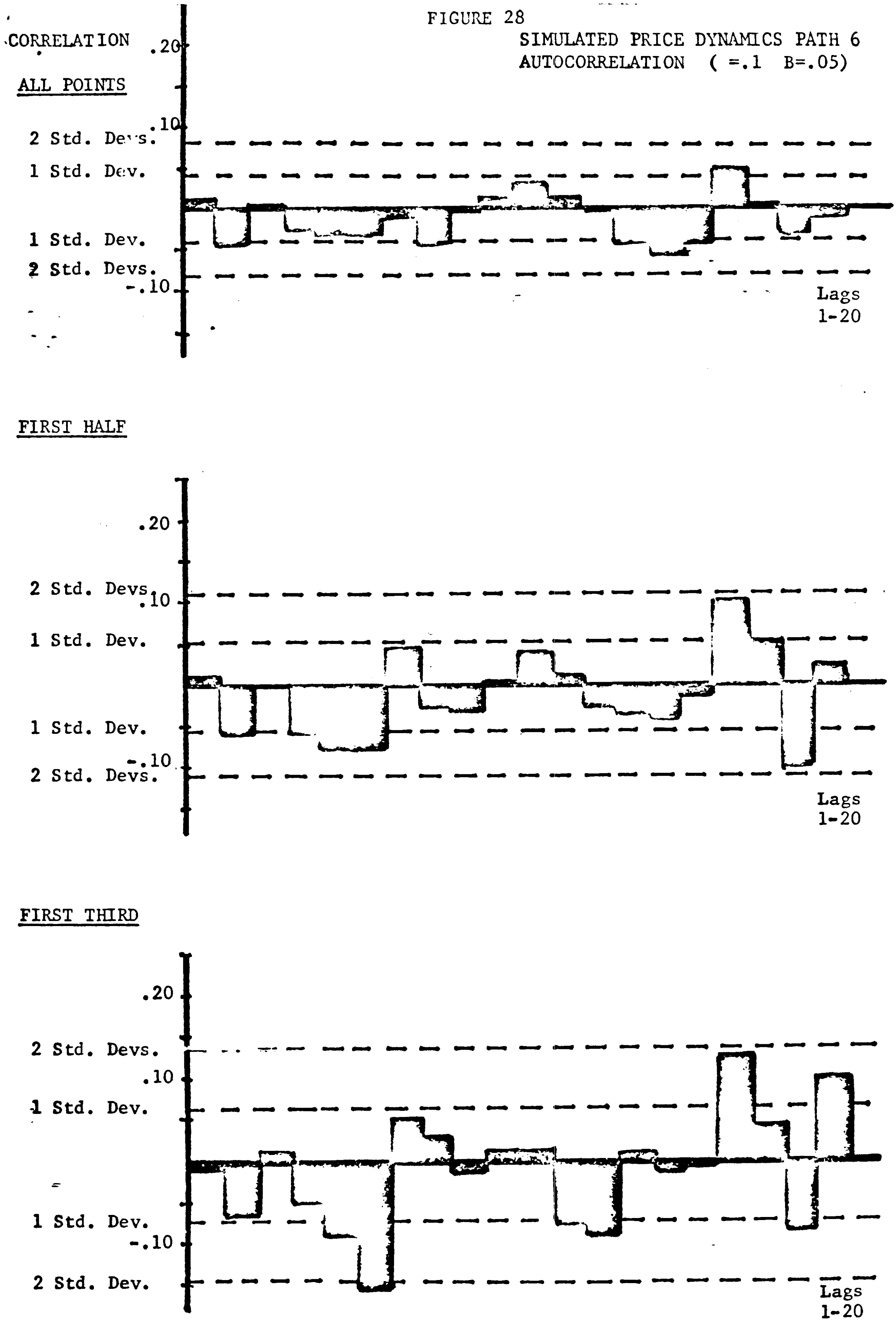


FIGURE 28

SIMULATED PRICE DYNAMICS PATH 6
AUTOCORRELATION (=.1 B=.05)



SIMULATED PRICE DYNAMICS PATH 7
AUTOCORRELATION (=.1 B=.1)

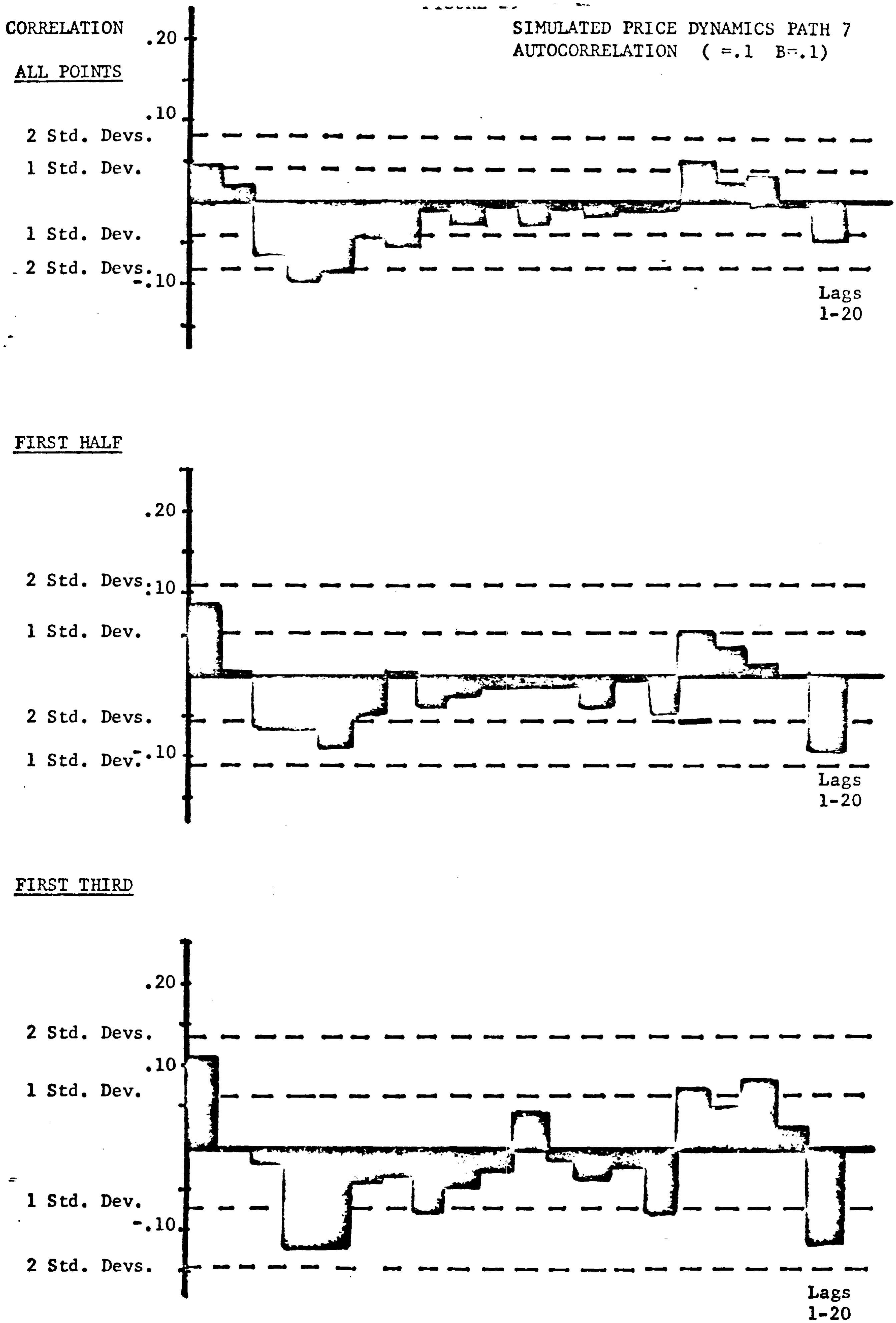


FIGURE 30

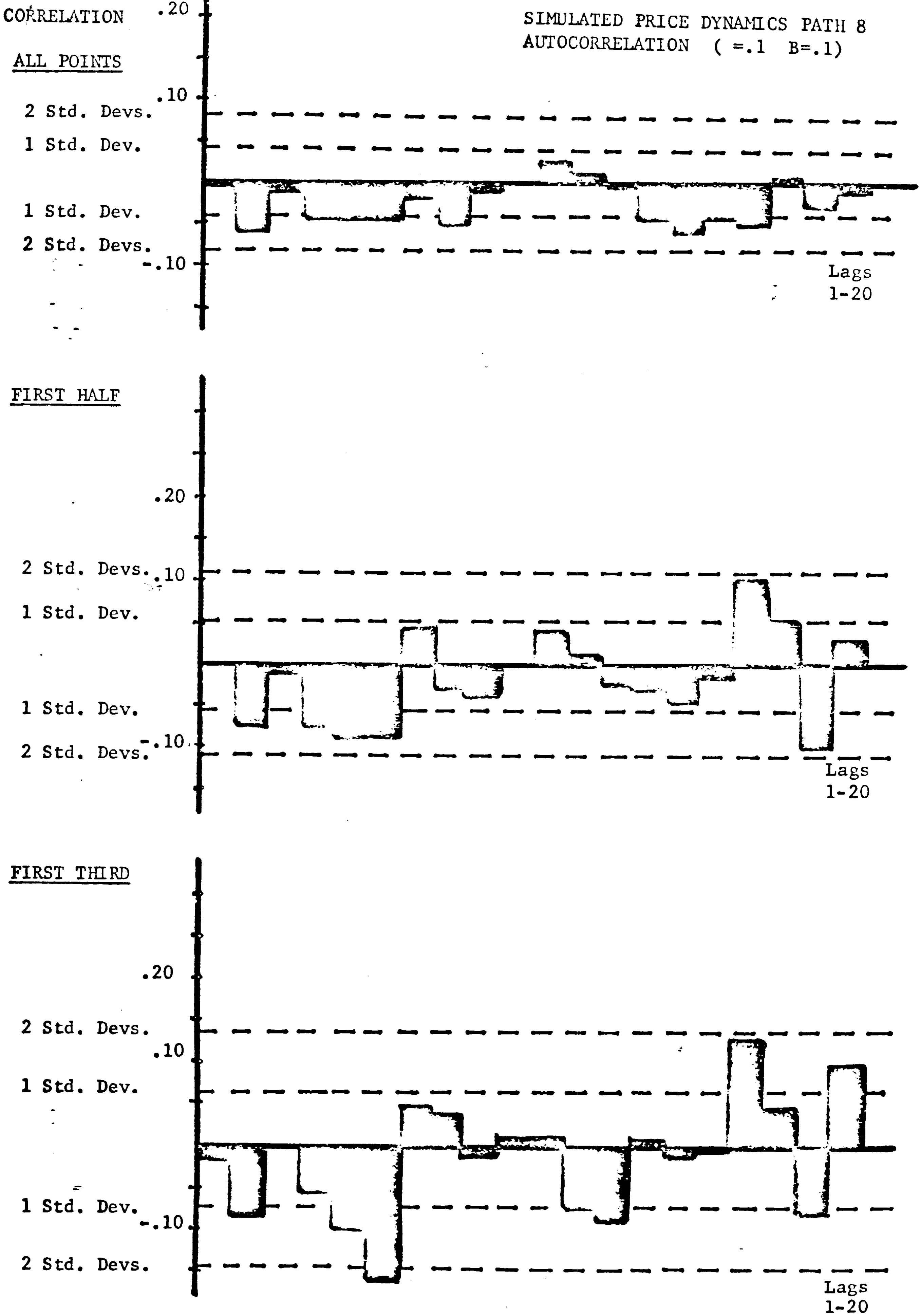

SIMULATED PRICE DYNAMICS PATH 8
AUTOCORRELATION (=.1 B=.1)
CORRELATION
ALL POINTS
.20
.10
2 Std. Devs.
1 Std. Dev.
1 Std. Dev.
2 Std. Devs.
-.10
Lags
1-20
FIRST HALF
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20
FIRST THIRD
.20
2 Std. Devs.
.10
1 Std. Dev.
1 Std. Dev.
-.10
2 Std. Devs.
Lags
1-20

FIGURE 51

SIMULATED PRICE DYNAMICS PATH 9
AUTOCORRELATION (=.1 B=.15)

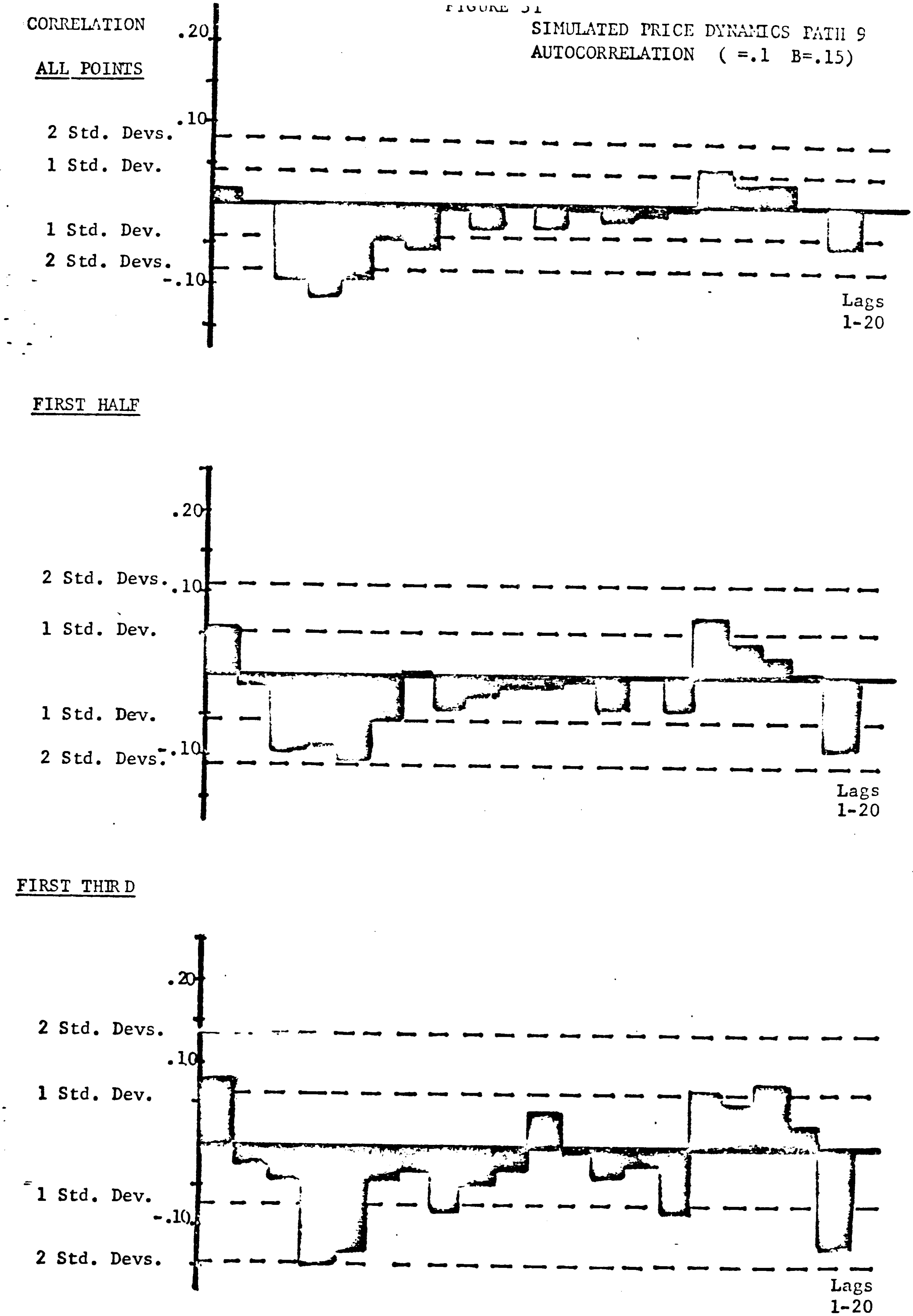
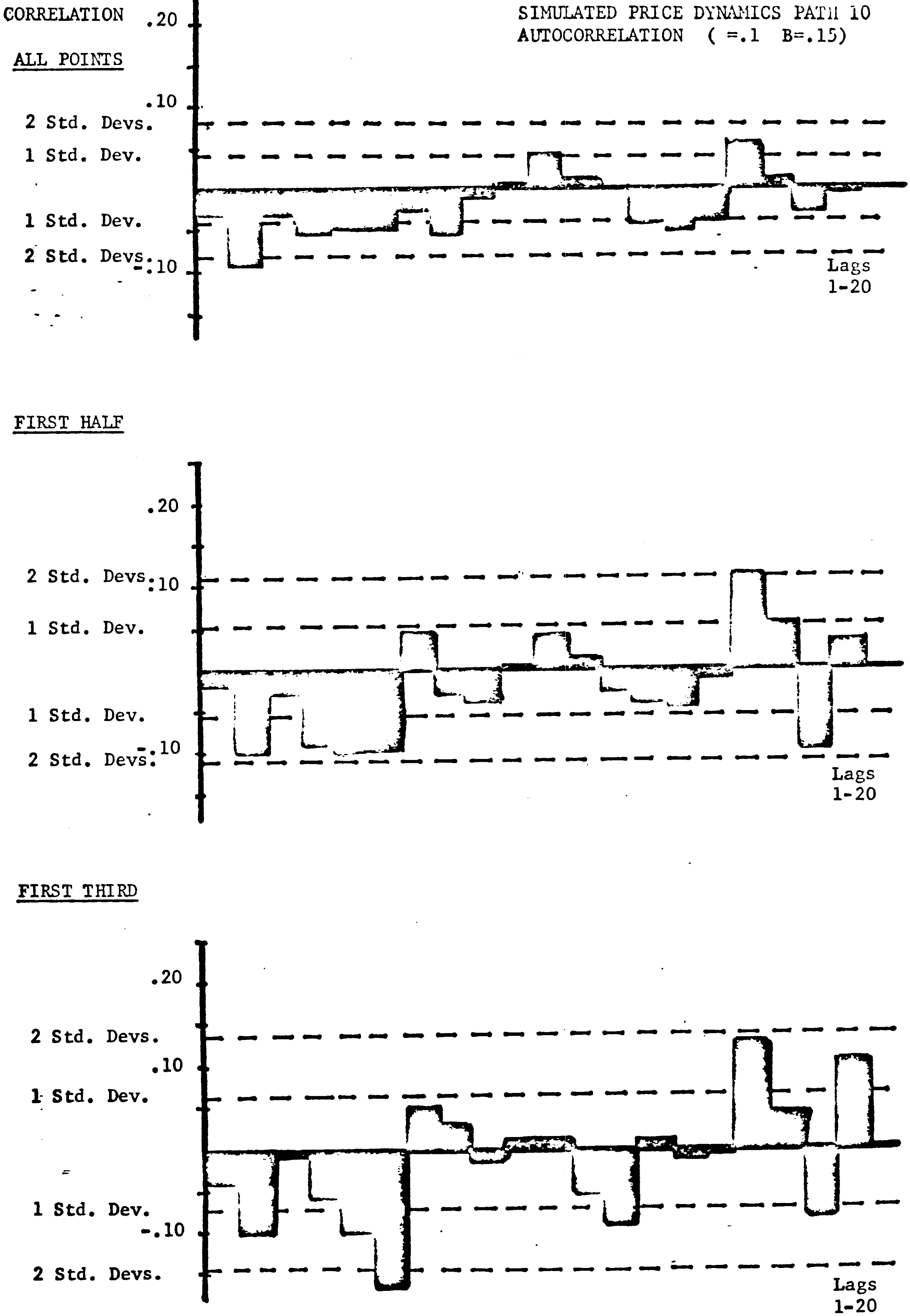


FIGURE 32

SIMULATED PRICE DYNAMICS PATH 10
AUTOCORRELATION (=.1 B=.15)



rejecting the martingale model when it is the true model. For the whole sample the martingale model can be rejected for four of the nine countries of the 95 per cent confidence level. The Q statistics generated for the known random walk paths are clearly smaller than those generated by the exchange rate data. For subperiods of the sample a finding for greater departures from the martingale model late in the sample period is clearly shown in Table 3. There were no significant values for Q (at the 90 per cent level) in the first third of the sample period and only one significant Q (for Japan) in the second third of the sample period.

Table 4 summarizes how many of the twenty computed sample autocorrelations in each case are more than one and more than two standard deviations from zero. Under the random walk hypothesis, the theoretical autocorrelations would be zero. For the six currencies examined, the mean number of sample autocorrelations more than one standard deviation from zero is between six and seven and the mean number of sample autocorrelations more than two standard deviations from zero is one. The probability is .01 that as many as 3 sample autocorrelations out of 20 will be more than 2 standard deviations from zero when the true value is zero and the probability is .002 that as many as 4 will be. The probability is less than .01 that as many as 11 sample autocorrelations will lie more

Table 3

Values of Q^{+} Statistics for Exchange Rates and Random Walk Paths

	All	1/2	2/2	1/3	2/3	3/3
Belgium	36 **	21.63	49.26***	22.81	12.34	44.51**
Canada	26.14	14.28	20.19	19.89	16.12	23.29
France	27.37	21.62	44.07***	26.32	22.08	37.18*
Germany	32.52**	21.10	20.81	24.15	17.16	19.62
Italy	28.42*	16.30	29.10*	21.89	19.43	26.43
Japan	21.12	11.89	33.98**	1.47	33.81**	21.43
Netherlands	39.93***	24.61	24.99	27.81	12.54	38.17***
Switzerland	29.34*	18.04	47.90***	15.25	25.74	36.63**
United Kingdom	36.87**	25.71	25.93	23.69	27.36	19.37
RW#1	12.99	8.93	12.93	14.03	12.02	10.43
RW#2	14.27	18.05	12.98	21.71	14.96	13.91
RW#3	15.87	23.53	18.99	28.87*	13.66	13.78
RW#4	18.97	10.03	15.97	8.12	20.17	18.65

*** Significant at 1% level, critical value = 37.6
** Significant at 5% level, critical value = 31.4
* Significant at 10% level, critical value = 28.4

$$Q = \sum_{i=1}^{20} \hat{a}_i^{\,2}$$

N = number of observations
a_i = sample autocorrelation of lag i
i = 1, ..., 20

Q is distributed as a chi-squared variable with 20 degrees of freedom.

Table 4

Number of Autocorrelations with Absolute Value
Greater Than or Equal to 1 and 2 Standard Deviations
(entire sample period)

	1 Standard Deviation	2 Standard Deviations
Belgium	10	3
Canada	8	2
France	9	0
Germany	11	2
Italy	8	1
Japan	5	1
Netherlands	10	4
Switzerland	7	3
U.K.	7	5
Random Walk #1	5	0
#2	4	1
#3	6	0
#4	5	1
Price Dynamics Path #1	7	1
#2	4	0
#3	9	3
#4	8	1
#5	8	1
#6	6	0
#7	8	2
#8	9	0
#9	7	3
#10	10	1

Using large sample estimate of the standard deviation correct under null hypothesis of zero autocorrelation; Standard deviation =

Table 4 Continued

	First Half		Second Half	
	1 Standard Deviation	2 Standard Deviations	1 Standard Deviation	2 Standard Deviations
Belgium	6	2	10	4
Canada	6	0	8	0
France	5	2	8	3
Germany	6	0	7	1
Italy	7	0	11	2
Japan	2	1	9	4
Netherlands	8	0	6	2
Switzerland	6	1	11	3
U.K.	9	1	9	1
(First Half only) Random Walk #1	2	0		
#2	6	1		
#3	8	1		
#4	4	0		
PDP #1	4	1		
#2	7	1		
#3	4	2		
#4	7	2		
#5	4	1		
#6	7	0		
#7	6	0		
#8	7	0		
#9	7	0		
#10	7	1		

Table 4 Continued

	First Third		Second Third		Final Third	
	1 Standard Deviation	2 Standard Deviations	1 Standard Deviation	2 Standard Deviations	1 Standard Deviation	2 Standard Deviations
Belgium	4	2	3	1	11	3
Canada	8	0	7	0	9	0
France	8	1	7	1	7	3
Germany	9	0	4	1	5	1
Italy	9	0	3	1	11	1
Japan	0	0	11	2	7	1
Netherlands	9	2	4	0	12	3
Switzerland	7	0	8	1	10	3
U.K.	9	0	9	3	7	0
(First Third) Random Walk #1	6	0				
#2	6	1				
#3	11	1				
#4	4	0				
PDP #1	7	1				
#2	6	1				
#3	9	1				
#4	7	2				
#5	7	0				
#6	7	1				
#7	8	0				
#8	8	1				
#9	8	1				
#10	7	1				

than one standard deviation from zero when zero is the true value. As may be seen in the table, the exchange rates in general have a high incidence of sample autocorrelations that differ from zero by more than the critical values. The exchange rates seem to exhibit at least as strong a pattern of autocorrelation as the simulated price dynamics paths. For the entire sample period only the exchange rate path for the Japanese yen is indistinguishable from the random walk paths in its number of sample autocorrelations that exceeds critical values. The smaller sample sizes for the halves and thirds of the sample period give rise to greater dispersion in the number of sample autocorrelations exceeding critical values, as may be seen from the results for the random walk paths. The incidence of sample autocorrelations that exceed critical values shows no tendency to decline in successive time periods. Rather, the total number of autocorrelations that exceed 2 standard deviations goes from 5 to 10 to 15 in successive thirds of the sample period.

In Figures 1 to 32 the sample autocorrelations are plotted. Although the number of sample autocorrelations that exceed critical values sugguests strongly that the exchange rate changes differ from a random walk, the patterns are weak enough and unstable enough that the plots do not provide much information concerning the nature of the non-randomness. All countries but Italy have negative sample autocorrelations for a 2 day lag in the full sample period, with those for the snake countries and Switzerland more than 2 standard deviations less than zero. The pattern of negative second sample autocorrelations is stronger in the first and last thirds of the sample period.

Except for the second, most sample autocorrelations are positive. Table 5 shows the number of positive autocorrelations (out of twenty) for each sample. There are clearly more positive sample autocorrelations in the exchange rate data than in the simulated random walk paths. Under the null hypothesis that the true autocorrelations are zero, the sample autocorrelations are independent and the number of positive sample autocorrelations will follow a binomial distribution. A 2-tail test for an individual series would reject the null hypothesis if the number of positive sample autocorrelations is greater than 14 or less than 6. All four random walk series show between 7 and 13 positive values while the exchange rate data contain many instances of 14 or more positive values.

A comparison of the pattern of sample autocorrelations for the exchange rate data with that for the price dynamics simulations makes it clear that the processes are different. Negative sample autocorrelations predominate. Nevertheless the strength of the processes in the exchange rate data -- that is, the magnitude of the moving average parameters --appears to be comparable to that of the price dynamics processes, except that values of α as large as .3 can be ruled out.

Table 5

Number of Positive and Negative Autocorrelations

	Positive	Negative
Belgium	16	4
Canada	15	5
France	14	6
Germany	17	3
Italy	15	5
Japan	11	9
Netherlands	15	5
Switzerland	10	10
U.K.	12	8
Random Walk #1	7	13
#2	13	7
#3	10	10
#4	10	10
Price Dynamics Path #1	7	13
#2	13	7
#3	6	14
#4	14	6
#5	5	15
#6	7	13
#7	5	15
#8	5	15
#9	4	16
#10	5	15

Table 5 Continued

	First Half		Second Half	
	Positive	Negative	Positive	Negative
Belgium	14	6	14	6
Canada	12	8	9	11
France	16	4	13	7
Germany	15	5	13	7
Italy	12	8	15	5
Japan	11	9	17	3
Netherlands	14	6	15	5
Switzerland	9	11	10	10
U.K.	10	10	12	8
(First Half only) Random Walk #1	9	11		
#2	8	12		
#3	11	9		
#4	8	12		
PDP #1	6	14		
#2	9	11		
#3	6	14		
#4	11	9		
#5	6	14		
#6	9	11		
#7	7	13		
#8	7	13		
#9	6	14		
#10	7	13		

Table 5 Continued

	First Third		Second Third		Final Third	
	Positive	Negative	Positive	Negative	Positive	Negative
Belgium	15	5	12	8	13	7
Canada	13	7	12	8	10	10
France	14	6	10	10	10	10
Germany	17	3	10	10	14	6
Italy	13	7	8	12	16	4
Japan	6	14	14	6	10	10
Netherlands	16	4	11	9	15	5
Switzerland	12	8	11	9	9	11
U.K.	14	6	9	11	11	9
(First Third) Random Walk #1	8	12				
#2	9	11				
#3	10	10				
#4	11	9				
PDP #1	8	12				
#2	10	10				
#3	8	12				
#4	12	8				
#5	7	13				
#6	9	11				
#7	6	14				
#8	9	11				
#9	6	14				
#10	8	12				

The price dynamics simulations provide the basis for a further observation. The pattern of sample autocorrelations for a given currency is relatively unstable over the thirds of the sample period. However, considerable instability also occurs between the first thirds of the two runs of each price dynamics case. Therefore, we do not consider the instability of the sample autocorrelations to be a very strong indication of instability of patterns in exchange rates. Since the distribution of the sample autocorrelations depends on the theoretical autocorrelations, a direct test of stability based on the sample autocorrelations is not possible.

There is some support for the hypothesis of a weekly pattern in the exchange rates for Japan, the Netherlands, and the U.K. Technical features of payment dates and reserve requirements for U.S. banks are known to make dollars delivered in clearing house funds for Thursday (contracted for on Tuesday) more attractive than dollar holdings on other days, other things being equal. It would therefore not be surprising if weekly exchange rate patterns reflected the relative returns from different currencies over the week. We have not determined yet whether the weekly patterns that may lie in the data are those that would be predicted by these considerations.

Our second test involved the sequences of signs of exchange rate changes. It provides only isolated evidence of non-random behavior. A formal test was performed to determine whether the total number of runs occurring in each sample was consistent with the hypothesis that the changes were independent. The results of this test for the actual exchange rates are reported in Table 6. They show that the hypothesis of randomness cannot be rejected for any country, although the absolute values for many of the standard normal variables are large.

There are several instances of runs of exchange rate changes in the same direction that are too long to have occurred by chance in the rates for the snake countries and Switzerland:

Belgium	15 days
Germany	11, 12, 16 days
Netherlands	11 days
Switzerland	11 days

We have not computed the unconditional probability of these runs occurring by chance, but the probability of a run of S or larger, conditional on the total number of runs, R, is

$$Pr\left\{S \geq s_c \mid R\right\} = .5^S R$$

The numbers of runs are clustered in the vicinity of 300. The probability of obtaining a run of 11 days is about .15 while the probability of a run of 15 days or more is about .01, conditional on there being 300 runs. This gives a crude indication of the probability of these events under the null hypothesis.

We have looked closely at the longest run -- the decline of the German mark on sixteen consecutive days, which coincides with the 15 day decline of the Belgian franc, and we found that during this episode, which occurred in December, 1973 and January, 1974, dollar/mark intervention was larger and more sustained than at any other time during the first fifteen months of flexible rates.

Table 6

Test on Number of Runs

Country	Z test statistic
Belgium	-1.79
Canada	-.91
France	-1.50
Germany	-.97
Italy	1.49
Japan	1.53
Netherlands	-1.58
Switzerland	-.92
United Kingdom	-.63

The Z test statistic is a standard normal variable computed from the formula (Siegel [1966]):

$$Z = \frac{r - \left(\frac{2n_1 n_2}{n_1 + n_2} + 1\right)}{\sqrt{\frac{2n_1 n_2 (2n_1 n_2 - n_1 - n_2)}{(n_1 + n_2)^2 (n_1 + n_2 - 1)}}}$$

A positive value for Z indicates that the number of runs in the sample exceeds the expected number for a random ordering. A negative value for Z indicates fewer than the expected number of runs. The hypothesis of random ordering may not be rejected with 95 per cent confidence if the value of Z lies in the critical region.

$$-1.96 < Z < 1.96$$

Although an important objective of intervention during this period was to take advantage of a strong dollar to adjust reserve levels, it appears that this episode was a successful example of leaning against the wind and thereby spreading what would otherwise have been an abrupt exchange rate adjustment over a four week period. The total change in the dollar/mark rate over this period was 10.6 per cent. The amounts of intervention were largest at the end of the period. On days near the end of the period when there was no intervention, exchange rate changes were large with over one half the total rate change taking place on two days. This suggests that the ability to hold down the rate through intervention was eroding over time.

The results of the third set of tests, the filter trading rules, are reported in Tables 7 and 8. The filter rules embody the price dynamics hypothesis that turning points in price series are followed by trends and that turning points can be identified by filtering out "small" reversals in exchange rates. The persistence of a trend is sometimes said to depend on the underlying psychology in the market. On individual days there are likely to be reversals or technical corrections but these "small" reversals do not signal a shift in the psychology of the market. The definition of "small" reversals is of course arbitrary, and we have tested filters ranging from one to fifty per cent.

Table 7

Filter Rules -- Average Annual Percentage Profits and Losses Adjusted for Interest Rate Differentials: March 1973 - September 1975

		.01	.03	.05	.10	.15	.20	.25	.50
FRANCE	All	15.98	10.89	20.59	8.49	-3.90	-0.07	-1.82	0
	1H	15.97	14.57	19.61	4.77	-3.73	0	0	0
	2H	12.48	9.11	13.97	3.10	-1.05	5.46	0	0
	1T	28.39	23.79	26.14	15.86	-1.85	0	0	0
	2T	3.50	-15.82	2.71	0	0	0	0	0
	3T	8.57	12.67	15.50	-1.11	-8.82	0	0	0
GERMANY	All	8.94	9.51	14.21	-3.45	-6.50	-14.66	-22.59	0
	1H	17.28	18.71	17.36	5.61	-9.34	-26.54	-32.38	0
	2H	0.04	3.63	10.04	0.44	-6.92	0	0	0
	1T	16.36	28.23	23.12	4.77	4.10	-10.65	-26.19	0
	2T	17.86	2.75	-0.87	-5.22	0	0	0	0
	3T	-0.95	-0.66	-3.89	0	0	0	0	0
JAPAN	All	2.79	5.08	0.86	-6.31	-2.25	-29.39	0	0
	1H	7.47	5.85	7.14	-3.05	-5.76	-7.15	0	0
	2H	-3.05	1.08	-2.20	0	0	0	0	0
	1T	9.99	15.54	11.68	7.69	-0.27	0	0	0
	2T	6.12	-1.51	5.24	-11.04	0	0	0	0
	3T	-5.22	-0.47	-3.30	0	0	0	0	0
NETHERLANDS	All	17.64	16.95	5.65	0.13	-11.73	-2.56	-4.18	0
	1H	30.35	22.51	12.15	-2.10	-21.51	0	0	0
	2H	6.36	12.00	1.50	-0.50	-7.71	0	0	0
	1T	37.34	19.81	15.58	3.59	-11.02	0	0	0
	2T	10.07	8.20	-16.08	0	0	0	0	0
	3T	4.32	16.08	12.30	-3.98	0	0	0	0
U.K.	All	5.39	8.00	0.55	-1.39	0	0	0	0
	1H	8.61	12.34	5.87	0.15	0	0	0	0
	2H	2.65	7.38	2.56	0	0	0	0	0
	1T	8.80	10.44	4.82	0	0	0	0	0
	2T	3.02	6.66	0.42	-2.55	0	0	0	0
	3T	7.53	11.10	3.85	0	0	0	0	0

Table 7 Continued

		.01	.03	.05	.10	.15	.20	.25	.50
Random Walk #1	All	-11.34	0.84	-5.46	-6.10	-4.56	0	0	0
	1H	-4.83	-4.18	-11.47	1.41	-2.82	0	0	0
	2H	-15.28	4.62	1.87	-9.83	2.85	-0.40	0	0
	1T	-6.11	-13.92	-10.35	0	0	0	0	0
	2T	-17.77	1.11	-2.02	1.35	0	0	0	0
	3T	-10.52	0.23	-11.23	-16.48	0	0	0	0
Random Walk #2	All	-6.95	10.02	20.11	16.67	10.12	2.85	-1.97	0
	1H	0.09	-1.08	8.41	3.78	-0.31	0	0	0
	2H	-11.75	10.21	21.03	25.53	21.28	16.18	13.03	0
	1T	-11.27	-3.32	3.33	0	0	0	0	0
	2T	11.23	15.95	26.88	2.22	0	0	0	0
	3T	-18.04	8.85	12.36	22.29	13.31	8.36	3.68	0
Random Walk #3	All	-14.20	-3.67	-7.22	-13.18	-1.69	0	0	0
	1H	-21.47	1.16	-7.37	-14.34	-3.27	0	0	0
	2H	-9.22	-10.87	-11.53	-10.43	0	0	0	0
	1T	-28.39	0.19	5.03	-14.95	0	0	0	0
	2T	-4.78	12.69	10.94	-23.25	0	0	0	0
	3T	-10.48	-12.97	-24.07	-7.76	0	0	0	0
Random Walk #4	All	-3.27	0.16	5.24	1.92	-9.66	-4.52	0	0
	1H	2.51	5.09	1.85	1.59	-9.98	-8.86	0	0
	2H	-7.25	-4.24	11.01	3.57	0	0	0	0
	1T	-4.20	7.25	4.60	-0.03	-6.18	-11.06	0	0
	2T	0.24	-10.75	-9.52	0	0	0	0	0
	3T	-8.10	7.46	11.97	11.83	6.56	-0.11	-4.54	0
PDP #1	All	-2.45	-6.30	-11.69	-3.43	-10.06	0	0	0
	1H	-1.32	-9.47	-17.83	3.14	-0.72	0	0	0
	2H	-1.59	-5.48	-7.95	-7.58	-13.63	0	0	0
	1T	-3.82	-22.23	-21.00	0	0	0	0	0
	2T	-7.98	3.23	0.50	1.58	-3.55	0	0	0
	3T	2.97	-2.50	-7.43	-8.33	-6.11	0	0	0
PDP #3	All	15.98	8.67	-9.48	2.79	-4.78	-13.85	0	0
	1H	23.12	6.32	-16.44	5.33	1.53	-1.58	0	0
	2H	10.06	8.26	-6.44	0.92	-7.67	-18.69	0	0
	1T	30.39	-8.03	-26.53	-5.10	0	0	0	0
	2T	4.22	18.07	-6.23	5.20	-0.11	-6.04	0	0
	3T	12.33	7.88	3.30	0.39	-1.72	-7.56	0	0
PDP #5	All	-9.59	-11.30	-19.47	-11.32	0	0	0	0
	1H	-8.89	-14.21	-16.72	-2.44	0	0	0	0
	2H	-8.74	-11.03	-26.91	-3.28	0	0	0	0
	1T	-12.56	-23.29	-10.73	0	0	0	0	0
	2T	-8.39	3.22	-3.39	-4.76	0	0	0	0
	3T	-9.77	-10.93	-29.68	-17.56	0	0	0	0

Table 7 Continued

		.01	.03	.05	.10	.15	.20	.25	.50
PDP #7	All	-7.89	-33.56	-24.55	0	0	0	0	0
	1H	-7.13	-30.10	-20.68	0	0	0	0	0
	2H	-6.72	-41.47	-33.20	0	0	0	0	0
	1T	-11.34	-38.66	-14.60	0	0	0	0	0
	2T	-7.09	-22.73	-7.81	0	0	0	0	0
	3T	-2.38	-31.82	-33.66	0	0	0	0	0
PDP #9	All	-14.34	-38.80	-28.15	0	0	0	0	0
	1H	-12.51	-36.12	-23.07	0	0	0	0	0
	2H	-17.08	-46.17	-36.19	0	0	0	0	0
	1T	-14.60	-40.61	-17.55	0	0	0	0	0
	2T	-7.69	-28.10	-11.77	0	0	0	0	0
	3T	-19.25	-39.74	-36.73	0	0	0	0	0

Table 8

Filter Rules -- Average Yearly Profits and Losses not Adjusted for Interest Rate Differentials March 12, 1973 - September 5, 1975

	.01	.03	.05	.10	.15	.20	.25	.50
BELGIUM All	10.19	13.27	14.11	3.33	-7.56	-2.25	-3.54	0
First Half	15.78	17.09	23.25	4.73	-13.55	0	0	0
Second Half	6.16	10.98	9.77	-2.43	-8.89	0	0	0
First Third	18.99	12.97	23.18	9.55	-4.43	0	0	0
Second Third	12.60	4.24	-2.35	0	0	0	0	0
Final Third	-0.23	16.24	9.90	-6.62	0	0	0	0
FRANCE All	14.46	10.22	19.17	7.67	-3.40	-0.50	-2.12	0
1H	15.96	14.57	19.64	4.77	-3.73	0	0	0
2H	11.91	8.23	12.69	1.86	-2.42	-6.14	0	0
1T	28.56	23.90	26.29	16.23	-1.48	0	0	0
2T	3.42	-16.54	1.85	0	0	0	0	0
3T	8.20	11.57	14.04	-2.62	-9.23	0	0	0
GERMANY All	8.72	9.26	14.33	-3.22	-5.93	-14.51	-23.21	0
1H	17.26	18.71	17.85	6.09	-9.22	-27.05	-33.04	0
2H	0.56	3.96	9.93	-0.48	-8.19	0	0	0
1T	15.87	27.82	23.45	14.62	3.93	-11.20	-27.56	0
2T	17.07	1.71	-0.83	-5.14	0	0	0	0
3T	-0.95	0.12	10.29	-4.97	0	0	0	0
ITALY All	8.01	7.15	1.22	0	0	0	0	0
1H	13.19	9.01	5.52	0	0	0	0	0
2H	3.00	4.60	-0.23	0	0	0	0	0
1T	11.27	13.69	7.07	0	0	0	0	0
2T	15.01	1.19	-4.62	C	0	0	0	0
3T	4.48	6.92	-0.34	0	0	0	0	0
JAPAN All	3.02	4.53	0.48	-4.55	-0.35	-1.03	0	0
1H	7.41	4.92	6.97	-2.97	-5.10	-6.53	0	0
2H	-2.65	1.11	-3.34	0	0	0	0	0
1T	10.03	14.63	11.78	7.80	-0.26	0	0	0
2T	5.79	-2.41	4.54	-11.34	0	0	0	0
3T	-5.18	0.39	-5.02	0	0	0	0	0
NETHERLANDS All	18.15	16.79	5.45	1.14	-10.61	-2.11	-3.77	0
1H	30.81	22.91	12.18	-1.25	-20.71	0	0	0
2H	6.04	11.86	0.84	-1.34	-8.75	0	0	0
1T	37.87	20.33	15.53	4.40	-10.16	0	0	0
2T	9.57	7.13	-16.01	0	0	0	0	0
3T	4.11	16.17	11.14	-5.01	0	0	0	0

Table 8 continued

	.01	.03	.05	.10	.15	.20	.25	.50
SWITZERLAND All	14.47	5.14	13.37	7.31	-2.43	-12.55	0.66	0
1H	18.18	10.58	24.14	3.94	-11.51	-29.97	0	0
2H	8.67	-1.33	1.96	3.87	-2.36	-5.20	-8.19	0
1T	17.74	14.51	26.65	10.80	0.24	-13.69	0	0
2T	17.86	-2.37	1.12	0	0	0	0	0
3T	11.33	-6.49	-9.57	-2.55	-12.32	0	0	0
U.K. All	15.22	8.34	1.15	-1.84	0	0	0	0
1H	9.45	12.54	6.14	-0.02	0	0	0	0
2H	3.53	7.73	2.89	0	0	0	0	0
1T	9.85	11.55	5.88	0	0	0	0	0
2T	3.08	5.68	-0.42	-2.84	0	0	0	0
3T	8.68	11.63	4.35	0	0	0	0	0

The results, presented in Table 7 have several striking characteristics. First, for the whole sample the 1, 3, and 5 per cent filters are remarkably profitable. For example, the 1 per cent filter for the French franc would have yielded an annual rate of return of 16 per cent over the two and one half year sample period. For all countries, the profitability of the 1 per cent rule was greatest in the first half of the sample period and for most countries the profitability was greatest in the first third. The 1 per cent rule showed losses for 2 of the 5 currencies in the last third suggesting that patterns for rate changes did exist but they were not stable over time. The declining profitability of the filters over sub-periods also suggests that information existing in price changes early in the sample period may have been recognized and exploited later in the time period. The results for the 3 and 5 per cent rules are qualitatively similar to those for the 1 per cent filter. On the other hand the very large filters show consistent losses. These are based on only a few transactions, but they do suggest that large swings in exchange rates tended to be systematically reversed during the sample period.

As with our other tests, the filters were applied to random and simulated price dynamics paths with the same variance as the average for the exchange rates. One can see in Table 7 that for the random number paths the filters were consistently unprofitable, due to transactions costs. For filters larger than 1 per cent, profits appear since the number of transactions, and hence the total transactions cost, is smaller. The range of gains and losses demonstrates the sizable potential for windfall gains and losses that exists when prices are as volatile as exchange rates were during the sample period.

Our generated price dynamics paths generally show losses greater than those from the random paths. This suggests that if these price dynamics paths were accurate models of actual exchange rate changes, profits or smaller losses could be made by reversing the filter rule -- that is, the foreign currency would be purchased when a trough is observed and sold after a peak. Since the filters were profitable for actual exchange rates, the losses shown for the price dynamics paths suggest that they are based on a wrong model of exchange rates.

Finally, in Table 8 the results of the same experiments for actual exchange rates are reported without taking into account interest differentials. It can be seen that the interest differentials that prevailed were not of any importance to the profitability of the rules. Table 8 also reports results for three additional countries for whom interest rate data was not available.

V. Where Matters Stand

Substantial evidence was presented in Part IV that leads us to reject the martingale model for spot exchange rates. The profitability of the filter rules further suggests that the deviations from a martingale are important and that exchange markets for many currencies may not have been efficient in the use of price information during the sample period. We have some pieces of evidence with which to begin a characterization of the price dynamics of exchange markets, but clearly more work is required before we have an understanding of exchange rate behavior that would lead to policy prescriptions, e.g. either to intervene more in specified ways or to eliminate intervention as it has been carried out up to now.

Interest differentials must be ruled out as the principal explanations for the deviations from a martingale. The magnitudes of the resulting predictable changes would be too small and taking them into account does not noticeably reduce the profitability of the filter rules. Weekly patterns require further study, but they are not likely to account for much of the departure from the martingale model.

Capital controls, under which price information may be correctly appraised while investors are unable to profit from it, have been present during the period. The United States however, has had no capital controls since January 1974 -- about one third of the way into the sample period. Moreover, extraterritorial markets have made positions in controlled currencies available to investors for most of the currencies we have studied. Inefficiency in exchange markets would imply that these "Euro" market facilities were not fully exploited by investors and additional factors would be needed to explain the foregone opportunities. Periods during which capital controls were perceived to be an important impediment to short-term capital flows were relatively rare during the sample period.[12/] Although fixed capital controls as a barrier to position-taking provide a poor candidate for the cause of unexploited price information, changing capital controls could be a source of shifts in effective currency demands that overwhelmed the capacity of the market to assimilate them in a short period of time. However, most capital control changes have been defensive and have tended to reduce rather than increase the position taking required for the market to clear. The effect of capital control changes on exchange rates during this period must be studied directly before a judgment can be made as to their role in causing exchange rate paths to deviate from a martingale.

Central bank intervention has been an important factor in exchange markets during this period. We identified the longest sustained run in the German mark rate with a period when substantial intervention tended to resist the direction of movement of the exchange rate. Other similar incidents might be identifiable, but much of the required information is not in the public domain. We do not know how much of the deviation of exchange rates from rates that would prevail in efficient markets should be ascribed to intervention.

The Japanese yen presents another picture. The yen/dollar rate is widely thought of as one of the most actively managed of the rates studied. Nevertheless there are almost no grounds on which to reject the martingale hypothesis for the yen rate. Moreover, the standard deviation of the changes in the logarithms of this rate is smaller than for any rate but the Canadian dollar rate.

Our empirical results may be explained, in part, by the existence of only a small pool of funds that have been actively managed for short-term profit in exchange markets. The volume of transactions in the markets is many billions of dollars per day, with large and often discrete shifts in demand associated with trade payments and long-term investment flows. Many of the largest non-government participants -- the major international banks and multinational firms -- have been generally conservative in taking exposed short-term foreign exchange positions. The views of governments and central banks have probably contributed to this behavior. Regulation has often inhibited or restricted the growth of participation by others. As a result, the market may not be deep enough for the size of the shocks to which it has been subjected.

The lack of position taking in exchange markets may be due to risks other than those of the rate's changing. Most important is the credit risk implicit in any foreign exchange contract. The Herstatt failure in late June, 1974 resulted in a marked drop in foreign exchange market activity as market participants grew wary of credit risks. This decline in activity could have resulted in less efficient exchange markets. This hypothesis receives little support from the data, however. The autocorrelations are most consistent with the martingale for the second third of the sample period from January to October, 1974.

The filters were most profitable in the first third of the sample period. The autocorrelations also showed deviations from what would be expected of a random series in the first third although less than in the last third. It would not be surprising if exchange markets in the early part of the floating dollar period were quite different from the theoretical model in which participants have a long history of observations to draw on. Patterns could persist for some time before they would be recognized as such. The authors first conducted the autocorrelation tests and the runs test on 15 months of data beginning in March, 1973. On the basis of those tests we concluded that one could not reject the weak efficient-market hypothesis. There is some support in the data for the hypothesis that the statistical process describing rate changes has been unstable. We may find that in the next year the rules that seemed to work for the historical data will fail and new patterns may distinguish next year's exchange rates from a martingale. When the elapse of time required to learn that an old trading rule has failed and to find a new one that works is considered, however,the new pattern may not constitute a genuine departure from efficiency. More theoretical study of the meaning of efficiency in a non-stationary environment will improve our understanding of this issue.

Footnotes

1/ See for example statements by commercial and central bankers presented at the May 1974 Williamsburg Conference devoted to assessing the experience with floating rates. See also McKinnon [1974], Kindleberger [1974], Bernstein [1974].

2/ MacKay [1932]

3/ Bell [1974]

4/ Charles A. Coombs [1973]

5/ A number of these studies are collected in Cootner [1964]

6/ For a proof of this proposition see Samuelson, P.A. [1965]

7/ The sample autocorrelations were calculated on changes in logarithms of prices in order to obtain a distribution of changes that was symmetrical. The advantages of analyzing logarithms of speculative prices are discussed in Fama [1965]. A consequence of using logarithms is that the results are the same whether one measures the dollar price of foreign currency or the foreign currency price of the dollar as the exchange rate. Slightly different results for absolute changes may be obtained when one measures the exchange rate each way. As a practical matter, however, the difference between absolute changes, per cent changes, and log changes are very small for daily data.

8/ The test statistic was evaluated using Lilliefors [1967] tables for testing normality when the variance is unknown. The mean of the distribution was assumed to be zero.

9/ Blattberg and Gonedes [1974] report similar findings for securities prices.

10/ Alexander [1961] first tested the profitability of rules of this type on common stock prices.

11/ If interest parity holds for forward exchange rates (and there is substantial evidence that it does) this process is equivalent to selling either dollars or foreign currency in the forward market.

12/ An indicator of whether capital controls are a constraint on capital flows is the extent to which Eurocurrency interest rates diverge from national money market interest rates.

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