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TIME SERIES MODELING OF MONTHLY GENERAL FERTILITY RATES

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ABSTRACT

An analysis of monthly U.S. general fertility rates, 1950-1983, reveals (a) significant calendar effects, (b) seasonality, (c) outliers, (d) significantly different behavior over different decades, (e) the effect of benchmarking population figures to the 1980 census.

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I. Introduction

The data in this study are monthly U.S. general fertility rates, i.e., number of births divided by number of women aged 15-44, for January, 1950, through September, 1983. The data through December, 1981, are final, whereas the data for 1982 and 1983 are provisional. The source of the data is the National Center for Health Statistics (NCHS).

Population Division personnel at the U.S. Bureau of the Census use these data for three major activities.

(a) Monthly estimates of annual rates are made to look for early warning signals that previous projections of annual rates and actual annual rates may differ substantially.

(b) Forecasts of monthly rates must be made to prepare new demographic projections because the current population estimates done by Census are more up-to-date than the birth data that come from NCHS. (This is not a criticism. The NCHS data depend on monthly reports from states, which can be rather slow in coming in. Compilation also takes time.)

(c) Each month, 1-, 2-, and 3-month ahead forecasts of birth totals are formed and used as controls in planning the Current Population Survey.

In applications (a) and (c), decisions need to be made quickly, but the most recent data available are only provisional. Thus it is important to discover the relationships, if any, between provisional and final data. Before such relationships can be studied, however, it is necessary to understand the stochastic behavior of the final data, which is the topic of this paper.

Questions of scientific interest arise concerning these final general fertility rates.

(a) Has the stochastic behavior of rates changed over time?

(b) Are there deterministic sources of variation in the rates, e.g. calendar effects, lunar effects, and benchmarking of population estimates to different censuses in different decades?

(c) To what extent are monthly rates seasonal?

(d) Are outliers many or few?

In this paper we will address some, but not all, of the questions raised above. Our major conclusions are that monthly general fertility rates are seasonal, calendar effects are significant, outliers are few, and the stochastic (ARMA) behavior of the rates changes over time.

II. Preliminary Modeling

The Box-Jenkins model building prescription of identification, estimation, and checking was applied to the data for the decades of the 50's, 60's, and 70's separately. Natural logarithms of the fertility rates were modeled to eliminate heteroscedasticity.

Inspection of a plot of the natural logarithms (Figure 1) revealed the changing character of the series over time. Modeling relatively homogeneous segments of the data seemed appropriate, especially in light of changing social and cultural influences (see, for example, Freedman (1979), Lee (1975), Ryder (1979), Tu and Herzfeld (1982), and Westhoff (1983)). Moreover, the population totals in the denominators of the general fertility rates are benchmarked to the most recent past census, so partitioning the data into decades makes sense.

The models thus obtained are displayed in Table 1. Note the difference in the model forms among the three segments, even at this preliminary stage of model identification. The associated residual autocorrelation functions have prominent spikes at an unusual set of lags: 14, 19, 21, 23, 27, 29, and 33 (see Figure 2). Our experience is that calendar variation is often associated with autocorrelation at otherwise inexplicable lags. [See Bell and Hillmer (1983) for a discussion of the effects of calendar variation.] The presence of calendar variation in fertility data is well documented. See Menaker and Menaker (1959) and Criss and Marcum (1981). Land and Cantor (1983) attempted a crude calendar effects analysis with ARIMA models, but with unsatisfactory results.

Following Bell and Hillmer (1983), models with calendar effects were fitted to the three decades of fertility rate data. In their notation, six calendar variables have the form (number of days of type i) minus (number of Sundays): T1 = (number of Mondays) - (number of Sundays), ..., T6 = (number of

Saturdays) - (number of Sundays). The seventh calendar variable measures the length of the month: T7 = number of days in the month. The program described by Bell (1983) was used to search for outliers, and terms for prominent outliers were also included in the models. An additive outlier (AO) is a pulse disturbance in the data at a fixed epoch t_0. A level shift (LS) outlier is a permanent shift in level of the data. Bell's program searches for these types of outliers (plus some others).

The models fitted to the 1960's and 1970's had the form

$$
\begin{aligned}
(1-B)(1-B^{12})Z_t = {} & \sum_{J=1}^{7} \beta_J (1-B)(1-B^{12}) TJ_t \\
& + \sum_{i \varepsilon \Omega} \alpha_i (1-B)(1-B^{12}) \xi_t^{(i)} + N_t
\end{aligned}
\tag{1}
$$

where N_t follows a stationary ARMA model, the TJ's are the calendar variables, $\xi_t^{(i)}$ is an appropriate outlier variable, and Ω is the set of time epochs at which outliers occur. In the model fitted to the 1950's the seasonality had to be handled differently because attempts to include a seasonal difference and a twelfth-order moving average parameter led to $\hat{\theta}_{12} = 1.00$, effecting a cancellation with the seasonal difference. This indicated deterministic, rather than stochastic, seasonality. Thus, the model for the 1950's has eleven seasonal indicators S1,...,S11 (for the months January through November), a constant term, and no seasonal difference. The model form is

$$
\begin{aligned}
(1-B)Z_t = &+ \sum_{J=1}^{7} \beta_J (1-B) TJ_t \\
&+ \sum_{s=1}^{11} \gamma_s (1-B) Ss_t + (1-B)\gamma_0 \qquad (2) \\
&+ \sum_{i \varepsilon \Omega} \alpha_i (1-B) \xi_t^{(i)} + N_t
\end{aligned}
$$

Table 2 displays the models which now include calendar and outlier terms. The residual autocorrelations for these models suggest no model inadequacy. Moreover, rough F-tests for the significance of the calendar variables were performed. The statistic was

$$\frac{[\text{RSS(no calendar var)} - \text{RSS(calendar var)}]/7}{\text{MSE(calendar var)}}$$

For testing purposes, the model with no calendar variation is the model in Table 2 with the coefficients of the calendar variables held at zero and the other parameters reestimated under this restriction. The value of the F-statistic for the 1970's model was 8.954. A tabled F-distribution with 7 and 197 degrees of freedom has 99-th percentile of about 2.8, so the null hypothesis of no calendar variation is clearly rejected. The same conclusion holds for the 1950's and 1960's.

There is some question as to the need for such an elaborate calendar effect regression. Conversations with NCHS staff revealed their impression that most of the variation could be explained by the tendency for births to be less numerous on weekend days than on weekdays. Menaker and Menaker (1959) found this effect more pronounced in private hospitals than in public ones where doctors are on call 24 hours a day. See Criss and Marcum (1981) and the references therein for extensive documentation of the weekend effect.

If the weekday/weekend effect dominates the calendar variation, then we may use the simpler model

$$(1-B)(1-B^{12})Z_t = \delta_1(1-B)(1-B^{12})K_t+\delta_2(1-B)(1-B^{12})L_t+N_t \quad (3)$$

where K_t = the difference between the number of weekdays and the number of weekend days in month t, L_t = the number of days in the month (equal to T7 in model (1)), and N_t is stochastic noise with ARMA structure. The model may contain outlier terms and again, the model needs modification to handle the non-stochastic seasonal in the 1950's.

In the models in Table 2 we replaced the seven-variable calendar components with the simpler two-variable component of equation (3) and reestimated the models. We then computed F-statistics of the form

$$\frac{[\text{RSS(2 calendar variables) - RSS(7 calendar variables)}]/5}{\text{MSE(7 calendar variables)}}$$

These F-statistics for the 1950's, 1960's, and 1970's were 2.29, 1.16, and 0.56. They support the hypothesis that the simpler, two-variable calendar component is a sufficient description of the calendar variation in the monthly fertility rates.

Finally, we remodeled the data using the reduced calendar component. The results are reported in Table 3.

III. Interpretation of Models

The models displayed in Table 3 are indeed different across the three decades. This observation corresponds to the qualitative impression mentioned earlier that one gets from a plot of the general fertility rates. The 1950's are a period of steady increase, the 1960's a period of rapid decrease, and the 1970's a period of leveling off. The 1960's and 1970's models both have the operator $(1-B)(1-B^{12})$. The 1950's have a deterministic seasonal pattern as well as calendar effects.

Comparison of Variance Estimates

If we compare the $\hat{\sigma}_e^2$'s for the different models (compare Tables 1 and 3), we see that the inclusion of calendar and outlier variables substantially reduces the variance estimates (48%, 15%, and 34% for the three decades). In the 1960's, going from the full set of calendar variables to the reduced set (compare Tables 2 and 3) results in a 16% increase in the variance estimate, though the F-test did not reject a reduced model. In the 1950's and 1970's the variance estimates for the full and reduced calendar component models are not much different.

Comparison of Parameter Estimates

Comparing the coefficients of the seven-variable calendar component ($\hat{\beta}_i$'s in Table 2), we see that while the magnitudes of the coefficients vary, in the two models for the 1960's and 1970's the signs of the coefficients are the same. The coefficients $\beta_1, \ldots\beta_6$ do not admit meaningful interpretations individually, and must be considered as part of the overall calendar effect. In contrast, the coefficients of the two-variable calendar component ($\hat{\delta}_i$'s in Table 3) have a behavioral interpretation as the impact of the weekend/weekday effect ($\hat{\delta}_1$) and the adjustment for leap-year Februaries ($\hat{\delta}_2$) [see Bell and Hillmer, (1983)]. Note again that the signs of $\hat{\delta}_1$ and $\hat{\delta}_2$ are the same for the 1960's and 1970's.

The ARMA components of the models in Tables 2 and 3 are not too similar for the 1960's and 1970's, as can be confirmed by computing the Ψ-weights. Thus, the type of deterministic calendar component specified in the model affects the characterization of the stochastic structure of the series. In addition, the type of ARMA model specified (possibly also the type of calendar component used) affects the outlier detection -- slightly different sets of outliers for the 1960's and 1970's are specified in Tables 3 and 2. Thus, the ARMA components of the models appear to interact with the calendar specification and the detection of outliers.

In summary, our analysis in Section III has shown that the monthly general fertility rates can be fitted by models that

a) display significant calendar effects primarily related to differing numbers of births on weekdays and weekend days

b) display seasonality of deterministic type in the 1950's and of stochastic type in the 1960's and 1970's

c) are subject to very few outliers

d) differ substantially from decade to decade, suggesting gradual behavioral shifts in the birth process over time

IV. The Effect of Benchmarking

Population estimates are benchmarked on the most recent past census, which is taken in years ending in zero. Different coverage rates in different censuses can cause variation in population estimates, and hence in fertility rates, that are unrelated to natural sources of variation. For example, coverage rates for the 1980 census were, on the whole, higher than for 1970. This could result in an apparent increase in population and decrease in fertility rates in the 1980's that is unrelated to real population shifts.

4.1 Testing for the effect of benchmarking

We shall use a test proposed by Box and Tiao (1976) to look for a shift between the 1970's and the 1980's. Only the 24 monthly observations from 1980 and 1981 will be used because this exhausts the final data available.

The minimum mean squared error forecasts of the 1980 and 1981 data were generated from December, 1979, using the 1970's model in Table 3. Let $\hat{\sigma}^2$ denote the residual mean square, and let $a_1, \ldots, a_{24}$ denote the forecast <u>errors</u> in 1980 and 1981. Box and Tiao's test statistic is

$$Q = \hat{\sigma}^{-2} \sum_{\ell=1}^{24} a_\ell^2,$$

which is referred to a $\chi^2(24)$ distribution for significance.

For our data the value of Q is 107.486. Because this statistic is significant, it is very likely that the 1980's data are different from those expected by extrapolating the 1970's model. Table 4, upper panel, shows the forecast errors and the standard errors of these forecast errors estimated using the 1970's model. A time series plot of the forecast errors (Figure 3) reveals that the <u>forecasts</u> are unbiased through February, 1981, but they are <u>too high</u> for the rest of the period. This suggests a level shift in the actual fertility rates which may or may not be due to benchmarking. Our hypothesis was that the benchmarking effect would show up as a level shift beginning in early 1980. The apparent shift in the data, which begins with March, 1981, could be signalling a change in the stochastic behavior of the data. As we have documented changing ARMA behavior across previous decades, we must admit that such changes could be confounded with any level shifts that may be present.

Another test for model shifts can be performed as follows. Fit the 1970's model in Table 3 to the data from 1/70 through 12/81. (Remember that 12/81 is the end of the final data series now available.) Part of the fitting process is to run Bell's (1983) outlier program which will presumably detect shifts. When this procedure was carried out, the program detected <u>AO</u> outliers at 2/81 and 11/81. The presence of an outlier at 2/81 corresponds to the impression we got from the forecast error plot that some change from the underlying 1970's model had occurred. How a certain kind of <u>outlier</u> in the series relates to the <u>forecast errors</u> is a question that will be addressed in a later paper.

Regardless of the details, however, the main conclusion is clear. We would be reluctant to use the 1970's model for data in the 1980's without some further modification.

4.2 Contrast with simple ARMA analysis

What would have been our conclusion if we had used the ARMA model in Table 1 (which lacks a calendar component) as our 1970's model? The Q statistic is 939.775, indicating a major shift and agreeing with the analysis in Section 4.1. Table 4, bottom panel, shows the forecast errors and their estimated standard errors for the Table 1 model. Twenty-one out of 24 errors are positive, indicating <u>forecasts</u> that are <u>too low</u> throughout 1980-81. Figure 3 shows the contrast between forecast errors from the two models. The results from the simple ARMA model of Table 1 suggest a level shift in the <u>opposite</u> direction anticipated by our benchmarking discussion and actually found after fitting calendar components! Thus, ignoring calendar variation in time series analysis would have resulted in erroneous conclusions.

V. <u>Comparison with Land and Cantor</u>

Land and Cantor (1983) presented an analysis of general fertility rates over the period 1950-1979. Our study differs from theirs in several important respects.

1. We checked for varying model form over time.
2. Our incorporation of calendar components from the time series literature was successful in modelling the

calendar effect.

The attempts of Land and Cantor to account for the calendar components by the operator $(1-B^{13})$ on the left-hand-side of their equation, induced the need for MA terms at lags 13, 14 and 15.

3. Our method of incorporating the calendar component led to forecasts which are not misleading for the out-of-sample period of the early 1980's.

Land and Cantor concluded that using the $(1-B^{13})$ operator was not an improvement, and the model with that operator exhibited inferior forecasting performance for the within-sample period December, 1976 to December, 1978.

VI. Conclusions

We have presented a model for monthly general fertility rates that includes a nonstochastic regression component to capture calendar effects and outliers and an ARIMA component to capture stochastic effects. These components are estimated jointly using efficient statistical methods that allow us to test for the significance of the various effects. Our approach would allow other nonstochastic components to be added to the model and tested for significance. We have shown how our comprehensive model can be used to detect shifts in the data and how less comprehensive models can lead to erroneous conclusions.

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Table 1. Univariate Time Series Models for Monthly Fertility Rates, Decades of the 1950's, 1960's, 1970's. (Standard errors in parentheses.)

1950's

$$\underset{(\pm.07)}{(1-.752B)}\underset{(\pm.09)}{(1+.348B^{12})}(1-B^{12})Z_t = e_t \qquad \hat{\sigma}_e^2 = .320 \times 10^{-3}$$

1960's

$$(1-B)(1-B^{12})Z_t = \underset{(\pm.10)}{(1-.260B^2)}\underset{(\pm.08)}{(1-.482B^{12})}e_t \qquad \hat{\sigma}_e^2 = .148 \times 10^{-3}$$

1970's

$$\underset{(\pm.09)}{(1+.244B^3)}(1-B)(1-B^{12})Z_t = \underset{(\pm.06)}{(1-.824B^{12})}e_t, \qquad \hat{\sigma}_e^2 = .225 \times 10^{-3}$$

Table 2. Models with Seven Calendar Variables and Outlier Variables, Decades of 1950's, 1960's, 1970's. (Standard errors in parentheses.)

	Decade					
	1950's		1960's		1970's	
Parameter	Estimate	St. Err	Estimate	St. Err	Estimate	St. Err
β_1	.0022	.0020	-.0001	.0013	-.0003	.0018
β_2	.0037	.0020	.0018	.0013	.0050	.0017
β_3	-.0036	.0020	.0028	.0013	.0009	.0018
β_4	.0020	.0020	-.0014	.0012	-.0005	.0018
β_5	.0039	.0020	.0017	.0013	.0033	.0017
β_6	-.0051	.0020	-.0016	.0012	-.0035	.0011
β_7	-.0058	.0067	.0051	.0037	.0021	.0064
α_1	-	-	-.0173	.0058	-.0416	.0124
α_2	-	-	-.0205	.0061	-	-
γ_0	.0009	.0004	-	-	-	-
γ_1	-.0245	.0059	-	-	-	-
γ_2	-.0195	.0157	-	-	-	-
γ_3	-.0204	.0059	-	-	-	-
γ_4	-.0742	.0054	-	-	-	-
γ_5	-.0587	.0059	-	-	-	-
γ_6	-.0118	.0054	-	-	-	-
γ_7	.0459	.0059	-	-	-	-
γ_8	.0650	.0059	-	-	-	-
γ_9	.0767	.0054	-	-	-	-
γ_{10}	.0313	.0059	-	-	-	-
γ_{11}	-.0061	.0054	-	-	-	-
Outliers:	None		AOJune62 AOApril67		LSNov71	

Noise models:

1950's $N_t = (1-\underset{(\pm.082)}{.4349}B^2-\underset{(\pm.083)}{.2442}B^3)e_t$, $\hat{\sigma}_e^2 = .157 \times 10^{-3}$

1960's $N_t = (1+\underset{(\pm.093)}{.2157}B-\underset{(\pm.095)}{.0269}B^2-\underset{(\pm.099)}{.3811}B^3)(1-\underset{(\pm.078)}{.5483}B^{12})$, $\hat{\sigma}_e^2 = .108 \times 10^{-3}$

1970's $N_t = (1-\underset{(\pm.0668)}{.7849}B^{12})e_t$, $\hat{\sigma}_e^2 = .149 \times 10^{-3}$

Table 3. Models with Two Calendar Variables and Outlier Variables. Decades of 1950's, 1960's, 1970's. (Standard errors in parentheses.)

	Decade					
	1950's		1960's		1970's	
Parameter	Estimate	St. Err	Estimate	St. Err	Estimate	St. Err
δ_1	.0018	.0004	.0017	.0003	.0028	.0003
δ_2	-.0004	.0069	.0032	.0042	.0022	.0053
α_1	-	-	-.0239	.0069	-	-
γ_0	.0009	.0004	-	-	-	-
γ_1	-.0233	.0060	-	-	-	-
γ_2	-.0237	.0160	-	-	-	-
γ_3	-.0192	.0060	-	-	-	-
γ_4	-.0755	.0055	-	-	-	-
γ_5	-.0577	.0060	-	-	-	-
γ_6	-.0121	.0055	-	-	-	-
γ_7	.0470	.0060	-	-	-	-
γ_8	.0657	.0060	-	-	-	-
γ_9	.0758	.0055	-	-	-	-
γ_{10}	.0323	.0060	-	-	-	-
γ_{11}	-.0066	.0055	-	-	-	-
Outliers	None		AOApril67		None	

Noise models:

1950's $$N_t = (1-\underset{(\pm.0800)}{.4207}B^2-\underset{(\pm.080)}{.2551}B^3)e_t, \qquad \hat{\sigma}_e^2 = .166 \times 10^{-3}$$

1960's $$N_t = (1-\underset{(\pm.10)}{.314}B^3)(1-\underset{(\pm.08)}{.477}B^{12})e_t, \qquad \hat{\sigma}_e^2 = .125 \times 10^{-3}$$

1970's $$(1+\underset{(\pm.09)}{.490}B^{12})N_t = (1-\underset{(\pm.10)}{.216}B^2)(1-\underset{(\pm.10)}{.32}B^{12})e_t, \qquad \hat{\sigma}_e^2 = .148 \times 10^{-3}$$

Table 4. Forecast Errors and Estimated Standard Errors, 1980-81.
(Logarithmic Scale)

Model From Table 3

Year	1	2	3	4	5	6	7	8	9	10	11	12
1980	-.0145	-.0118	-.0040	-.0164	-.0040	-.0026	-.0061	-.0066	-.0024	-.0152	-.0158	-.0194
	(.0122)	(.0172)	(.0197)	(.0219)	(.0238)	(.0257)	(.0274)	(.0290)	(.0305)	(.0320)	(.0334)	(.0347)
1981	-.0098	.0223	-.0504	-.0453	-.0255	-.0422	-.0251	-.0273	-.0391	-.0114	-.0508	-.0328
	(.0367)	(.0385)	(.0402)	(.0417)	(.0432)	(.0447)	(.0461)	(.0475)	(.0488)	(.0501)	(.0514)	(.0526)

Model From Table 1

Year	1	2	3	4	5	6	7	8	9	10	11	12
1980	-.0065	.0615	.0468	.0597	.0363	.0810	.1684	.1593	.1589	.0326	-.0049	-.0028
	(.0150)	(.0212)	(.0260)	(.0320)	(.0370)	(.0414)	(.0454)	(.0491)	(.0525)	(.0557)	(.0588)	(.0617)
1981	.0294	.1187	.0354	.0294	.0415	.0761	.1816	.1711	.1529	.0601	-.0025	.0088
	(.0652)	(.0686)	(.0718)	(.0751)	(.0782)	(.0843)	(.0842)	(.0870)	(.0897)	(.0923)	(.0949)	(.0974)

Figure 1: Natural logarithms of monthly general fertility rates, 1950-1979

NATURAL LOGARITHM OF MONTHLY FERTILITY RATES BY DECADE

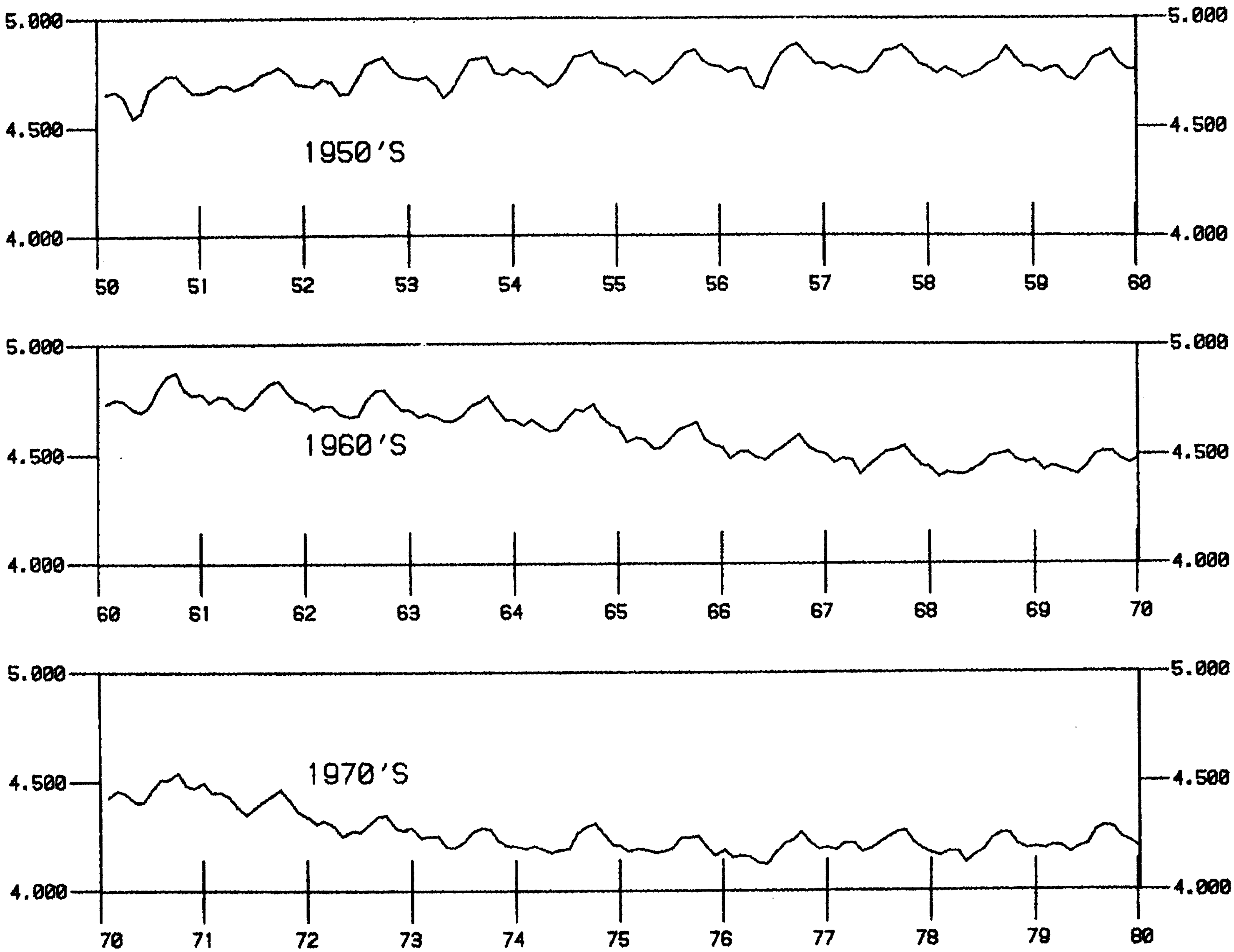


Figure 2. Sample Autocorrelation Function of Residuals from 1970's Model in Table 1. (Dotted lines are approximate long-lag two standard error limits.)

RESIDUAL AUTOCORRELATION FUNCTION, 1970'S MODEL FROM TABLE 1

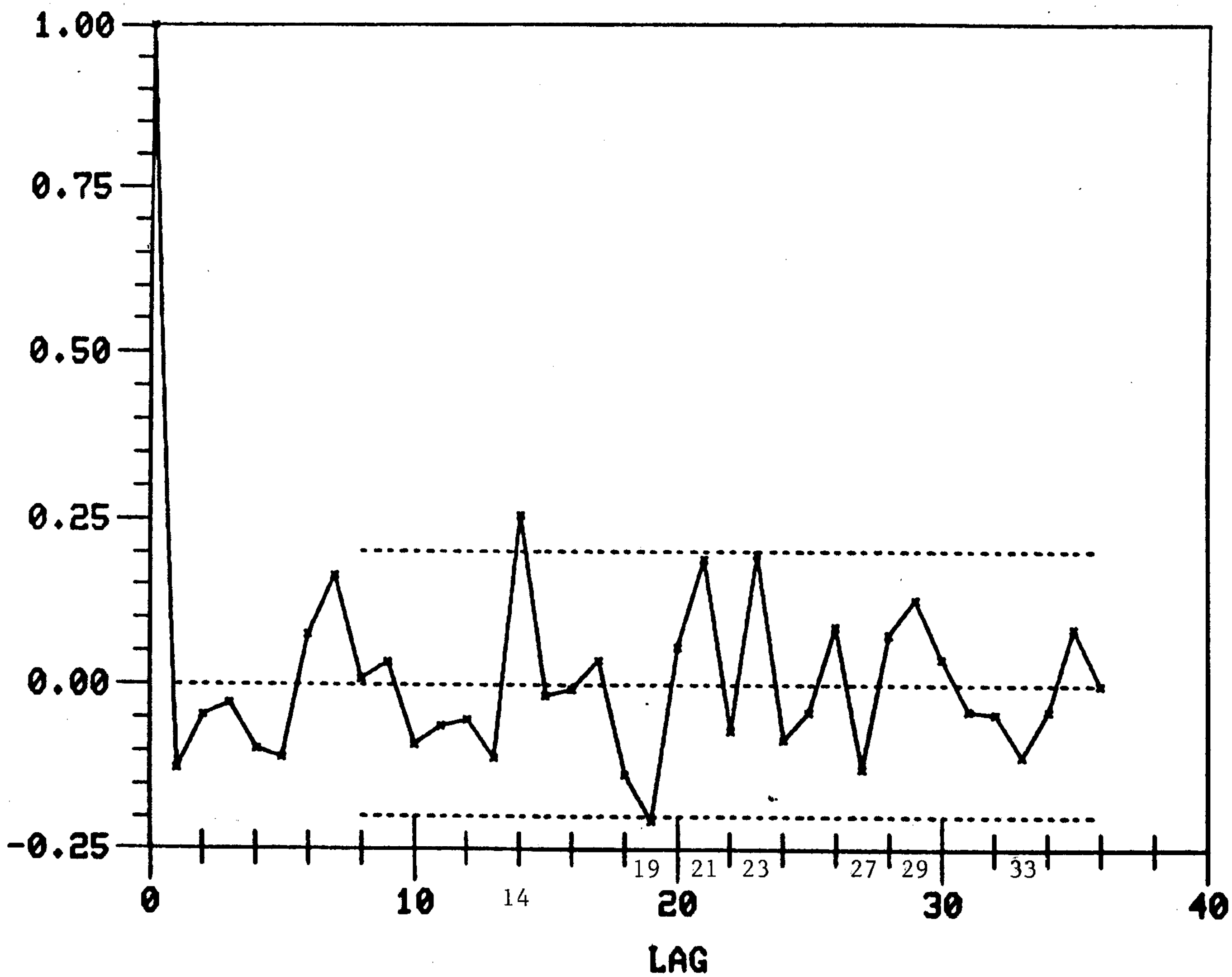
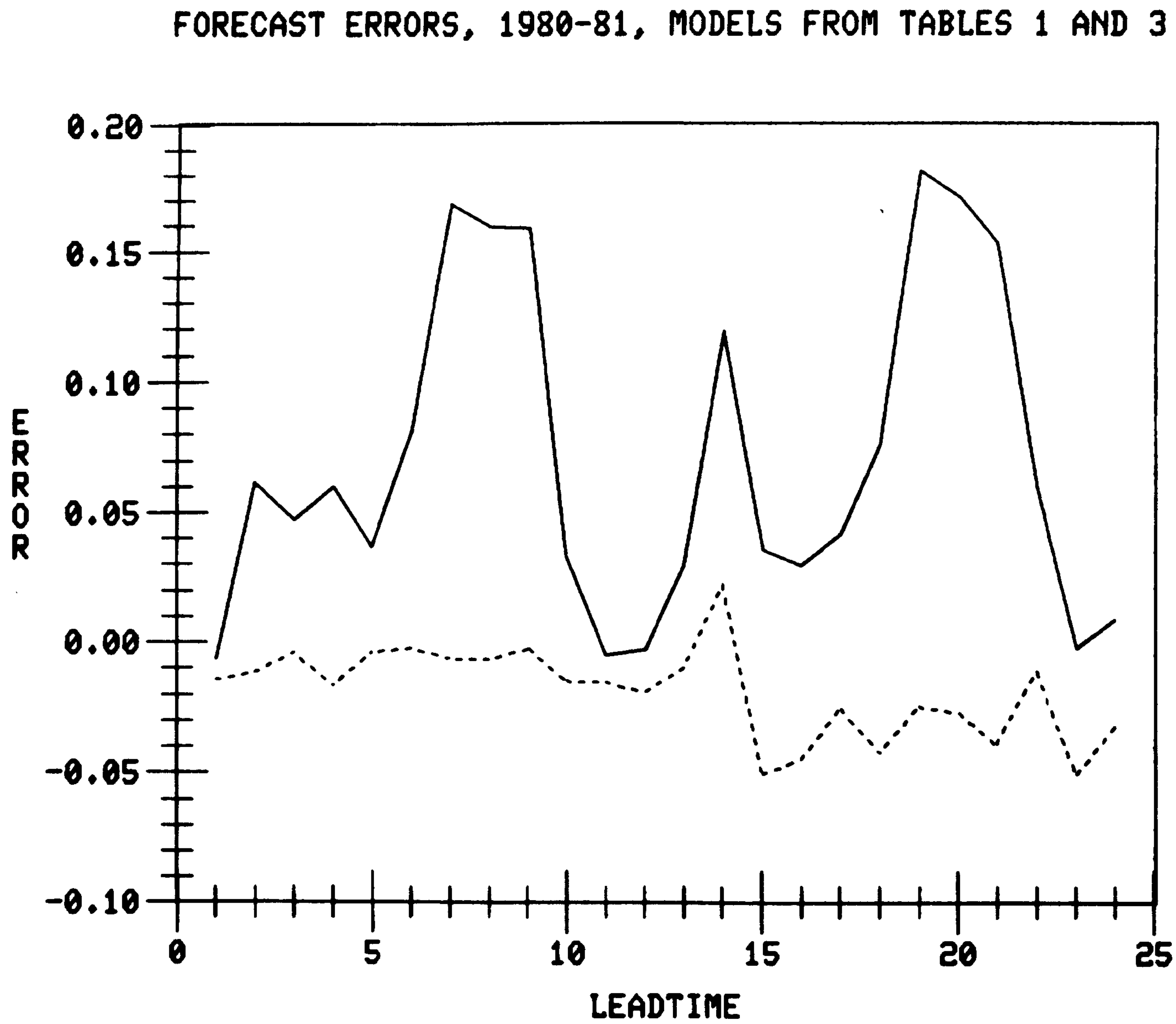


Figure 3. Time Series Plots of Forecast Errors, 1980-81. Forecasts from:
a) 1970's Model in Table 3 (dotted line)
b) 1970's Model in Table 1 (solid line)


FORECAST ERRORS, 1980-81, MODELS FROM TABLES 1 AND 3
ERROR
LEADTIME
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0
5
10
15
20
25