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INVESTIGATING LUNAR CYCLES IN MONTHLY FERTILITY RATES

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Investigating Lunar Cycles in Monthly Fertility Rates

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ABSTRACT

In order to test for the presence of full moon effects on birth and conception, deterministic regression components are added to previously developed time series models for monthly U.S. general fertility rates. These time series models included a stochastic ARIMA component and other deterministic components for outliers and calendar effects. The components are estimated jointly using efficient statistical procedures and statistical tests are carried out to determine the significance of the lunar component. No significant lunar effects are found.

* This work was carried out while the author was a mathematical statistician at the U.S. Census Bureau.

I. Introduction

Many people may dismiss the belief that more births occur on days where the moon is full as an old wive's tale but many delivery room nurses will attest that the number of women going into labor and giving birth does seem to increase during the full moon. This phenomenon of allegedly increased deliveries at the time of a full moon is commonly alluded to as the lunar effect. The behavior of the moon is certainly related to the human development process in other ways. The average human gestation period is precisely 9 $\pm$ .01 lunar months. (A lunar month consists of approximately 29.53 days.) The average female menstrual cycle is exactly 1 $\pm$ .01 lunar months with ovulation occuring half way through the cycle.

The literature abounds with attempts to document lunar effects in fertility data. The first documented work was a nonstatistical study by Schnurman (1947) who tried to associate one prominent moon phase with the highest number of births but found unusually high births were not restricted to any one phase. Rippman (1957) in a study with no statistical basis examined single days with a high number of births recorded and found they did not correspond to days with a full moon. On the other hand Menaker (1967) found the lunar half-cycle with the highest birth rates centered on the full moon. Menaker and Menaker (1959) examined birth rates in consecutive 3-day periods and found the most prominent birth rates fall on the day before, day of, and day after a full moon. This marked the introduction of the concept of a window about the full moon day. A window consists of a period of days before, during, and after an event over which it is thought the effects of the event may be spread. McDonald (1966) examined windows around the four main moon phases (full, new, and two quarters) consisting of the two days before, the day of, and the day after each phase. It was found that most births centered on the full moon, followed by the new moon, with the least on the quarters. Osley, Summerville, and Borst (1973) measured a lunar effect that was near the boundary of statistical significance but not in it. Throughout this paper the α=.05 level will be used to discern statistical significance. Abell and Greenspan (1979) found that the mean number of births on full moon days was not statistically higher than on all other days. Criss and Marcum (1980) tried a different approach. They performed a frequency analysis of birth data and noticed a small peak (not statistically significant) at the lunar period. However cross-correlations between birth rates and a generated sine wave following the lunar cycle were statistically significant.

With so many people believing in the full moon effect and so much evidence of its existence, we owe it to ourselves to check for its presence in the monthly fertility rate data. Several aspects of our analysis differ from these preceding studies. First, we did not restrict our attention to labor and the birth process. We allowed for the possibility that the full moon may be associated with or have an influence on conception. Second, previous studies have always examined daily data at a local (hospital, city, or county) level whereas our data consisted of nationwide monthly fertility rates. Since the phases of the moon are usually referred to in units of days, daily birth counts might actually be more appropriate. Having birth data on a nationwide basis is certainly advantageous because focusing on one area which may not be representative of the nation could lead to biased results. (For example, the theory of photosensitivity (Criss and Marcum, 1981) suggests that the increased illumination brought about by a full moon may stimulate ovulation and thus increase the number of conceptions. However, most of the studies above used birth records from New York City where the moon can rarely be seen and certainly provides very little illumination with all the bright city lights.) Third, no previous study has attempted to model the birth rate data in conjunction with testing for a lunar effect. The analyses and statistical tests they perform all assume the data is independent over time. Being time series, the errors are serially correlated over time. We applied a deterministic regression component to capture the full moon effect that was estimated jointly with the previously developed time series models for the fertility data that take into account the correlation structure of the error terms (Miller and McKenzie, 1984). Fourth, it was decided to define the full moon period as a window about the day of the full moon. Not knowing how the moon could be influencing the birth process, we had little clue as to how to quantify the full moon effect. Explanations run from the increased light intensity caused by the illumination of the full moon to the gravitational pull exerted by the moon's proximity. Depending on which, if any, of the explanations one finds plausible, the choice should dictate the appropriate full moon window to use. Having no insights on the issue, we considered various windows (symmetric, asymmetric, short, long) about the full moon day in our parameterization of the full moon effect. Quarter moon and new moon days were not considered.

This study will apply a deterministic regression component to attempt to capture the full moon effect that will be estimated jointly with the time series models previously developed by Miller and McKenzie for the fertility data. These models consist of an ARIMA component for stochastic effects and other deterministic components for other calendar effects and outliers. The main result was that no significant lunar effect could be found in the general monthly fertility rates.

II. Modelling

Miller and McKenzie (1984) laid the groundwork for this study by modelling and analyzing monthly general U.S. fertility rates, i.e. number of births divided by the number of women of childbearing age (approximately 14-44 years old). Data was available from 1950 to the early 1980's and they examined each decade separately. Their models for the logarithm of the fertility rates, Z_t, include an ARIMA component to capture stochastic effects, a deterministic regression component to capture calendar effects, and deterministic regression components for outliers to make the model robust to extreme observations. See also Land and Cantor (1983) for other work in modelling similar data.

The phases of the moon are continuously shifting, in fact, the full moon actually only lasts an instant. Typically the phases of the moon are referred to in units of days, the day within which the full moon falls being the full moon day. For our purposes we will use a block of days around the full moon and refer to it as the full moon window. Since we are trying to estimate a daily effect in monthly data, we must consolidate the lunar information into a monthly quantity. Therefore the monthly effect will consist of the number of days in the full moon window that fall within the month in question. References to several different windows can be found in the literature. Previous lunar studies had examined a 3-day symmetric window centered on the full moon day and an asymmetric window including the two days before, the day of and the day after. Asymmetrical windows have also been successfully used to model holiday (especially Easter) effects where there seems to be a period of increased buying preceding the holiday but no such behavior after the holiday (see, for example Bell and Hillmer (1983) and Cleveland and Grupe (1983)). We decided to try a variety of windows, having no prior expectations for any of them. In general, w_{ij} will denote a window about the full moon day consisting of all days in the period (full moon day - i, full moon day + j) inclusive.

Three parameterizations of the full moon effect were considered. First, to test for an association with births we define

$$B_t = \text{number of days from month t in a full moon window } (w_{ij}).$$

Second, if

bc_t = beginning day of month t lagged by exactly 9 lunar months

ec_t = ending day of month t lagged by exactly 9 lunar months

then $[bc_t, ec_t]$ is roughly the period of conception for all births in month t. To test for an effect on conception we define

C_t = number of days in conception period for birth month t that fell in a full moon window (w_{ij}).

We also considered a cruder conception period

Lag_9B_t = number of days in month t-9 that fall in a full moon window, i.e. lagging by exactly 9 calendar months.

Due to the proximity of lunar months to calendar months the lunar effect characterized by any of these three variables is fairly stable for most months. Only when a full moon window falls at the beginning and/or end of a month will there be more or less than one complete full moon window (i+j+1 full moon days) contained in that month. We initially considered the 5-day symmetric window consisting of the day of the full moon and the two days before and after, denoted w_{22}. If FM denotes the day of the full moon then

$$w_{22} = [\ FM-2,\ FM-1,\ FM,\ FM+1,\ FM+2\ ]\ .$$

Also considered were windows w_{11}, w_{44}, w_{24}, and w_{42}.

Deterministic lunar effects were incorporated into and jointly estimated with two of the sets of models for each decade, those with a 7-variable calendar effect and those with a 2-variable calendar effect. Also introduced and examined was a 3-variable calendar representation for weekday, Saturday, and Sunday effects where T1 = (number of weekdays) - (number of Sundays), T2 = (number of Saturdays) - (number of Sundays), T3 = number of days in the month. Various combinations of full moon windows and types of lunar effects (birth, conception, and crude conception) were investigated.

Since the lunar variables and the calendar variables both depend on the calendar composition there is a possibility the two effects could be confounded. A portion of the lunar effect may be explained by the calendar variables. To investigate, attention was focused on the decade of the 50's and the window w_{22}. The correlation between the calendar variables and the lunar variable was not large. Furthermore, we estimated models with both lunar and calendar variables and then models with only the lunar variable and models with only the calendar variables. The presence of the lunar variable did not alter the significance or the parameter estimates of the calendar variables as estimated in Miller and McKenzie. Neither was the significance of the lunar variable affected by the presence of calendar variables. It was assumed that the relative independence would carry over to the 60's and 70's data although no tests were carried out to verify this.

The model considered for the 50's is of the form

$$(1-B)Z_t = \underbrace{\sum_{J=1}^{ntd} \beta_J (1-B) TJ_t}_{\text{(calendar)}} + \underbrace{\sum_{s=1}^{11} \gamma_s (1-B) Ss_t}_{\text{(monthly means)}} + \underbrace{\gamma_0}_{\text{(constant)}}$$

$$+ \underbrace{\delta (1-B) C_t}_{\text{(lunar)}} + \underbrace{(1-\theta_2 B^2 - \theta_3 B^3) e_t}_{\text{(ARIMA)}}$$

where ntd is the number of calendar variables included in the model, TJ_t are the calendar variables, Ss_t are fixed seasonal effects, γ_0 is a constant term, B is the backshift operator, and e_t is the error term. To test for the significance of the lunar birth effect or the crude lunar conception effect, B_t or $Lag_9 B_t$, respectively, may be substituted in place of the lunar conception effect, C_t. Rough t-tests were performed on the parameter δ. The t-statistics are compared to a tabled value of 1.98 for significance at the $\alpha = .05$ level. Results are summarized in Table 1.

The results displayed in Table 1 reveal several interesting observations about the lunar effects. First, the lunar birth and conception effects were not found to be statistically significant but the crude conception effect borders on being significant.

Since the crude conception effect is just that, a crude attempt to quantify a conception effect, and the more precisely defined conception effect was not close to being significant, we cannot claim to have found a statistically significant lunar effect in the fertility data. Second, the parameterization of the calendar effect does not seem to affect the estimated value of any given lunar variable or its significance. Any differences between the variance estimates $\hat{\sigma}_e^2$ is due only to the number of calendar variables present. In fact, in comparing the values $\hat{\sigma}_e^2$ with those obtained from Miller and McKenzie's 50's model ($\hat{\sigma}_e^2 = .157 \times 10^{-3}$ for the 7-variable calendar model and $\hat{\sigma}_e^2 = .166 \times 10^{-3}$ for the 2-variable calendar model) one notices that the lunar birth and conception variables make no contribution at all towards reducing the variance estimates. The inclusion of the crude conception effect reduced the variance estimate by 16-18%. Perhaps the crude conception effect is confounded with some other effect which does influence the fertility rates.

Since it made little or no difference how many calendar variables were included in the model, further analyses considered only the 7-variable calendar parameterization. Table 2 displays the results of applying various full moon windows to the 50's data with 7 calendar variables. The only combination that produced a statistically significant lunar effect was the w_{11} window with conception. This result is somewhat surprising considering that the conception effect was not significant for any other window nor did any other lunar variable prove significant with the w_{11} window. It is interesting to note that with other full moon windows the crude conception effect was not found to be significant. There did seem to be some differences in lunar parameter estimates, $\hat{\delta}$, depending on which full moon window was used. No clear patterns emerged, however.

The same procedures were applied to data from the 60's and 70's decades with the appropriate models chosen by Miller and McKenzie. A smaller set of calendar variables and full moon windows were considered in light of the outcomes observed in the 50's data. Only the w_{22} and w_{11} windows were considered and only the 2-variable calendar effect was included. The model forms are

$$\text{(1960's)} \quad (1\text{-}B)(1\text{-}B^{12})Z_t = \underset{\text{(calendar)}}{\sum_{J=1}^{2} \beta_J (1\text{-}B)(1\text{-}B^{12})TJ_t} + \underset{\text{(lunar)}}{\delta(1\text{-}B)(1\text{-}B^{12})C_t}$$

$$+ \underset{\text{(outliers)}}{\sum_{i\in\Omega} \alpha_i (1\text{-}B)(1\text{-}B^{12})\xi_t^{(i)}} + \underset{\text{(ARIMA)}}{(1\text{-}\theta_3 B^3)(1\text{-}\theta_{12}B^{12})e_t} .$$

$$\text{(1970's)} \quad (1\text{-}B)(1\text{-}B^{12})Z_t = \underset{\text{(calendar)}}{\sum_{J=1}^{2} \beta_J (1\text{-}B)(1\text{-}B^{12})TJ_t} + \underset{\text{(lunar)}}{\delta(1\text{-}B)(1\text{-}B^{12})C_t}$$

$$+ \underset{\text{(ARIMA)}}{\left[\frac{(1\text{-}\theta_2 B^2)(1\text{-}\theta_{12}B^{12})}{(1\text{-}\phi_{12}B^{12})}\right] e_t} .$$

As before, any other lunar component may be substituted for the conception effect C_t. Results are summarized in Table 3. Again it is clear that no significant lunar effect is present in these decades either.

One possible criticism about the analysis may be the division of the data by decades. On one hand this breakdown is sensible from a definitional point of view because the number of women of childbearing age (the denominator of the general fertility rate) is re-estimated each decennial census and therefore is only consistent within a decade. On the other hand there may be some other breakdown of the fertility rates that more naturally lends itself to the data. For example, changes in public attitudes toward childbearing or delivery room procedures might suggest a different division of the data. Subject matter experts suggested dividing the data according to trend patterns.

Figure 1 shows the logarithm of the monthly general fertility rate over the entire span of data available. Natural breakdowns are apparent. From 1950 to about 1960 the rates are slowly increasing but overall fairly stable. 1960 to 1967 marks a period of sharp decrease. After a 3 year interruption where the rates level off the decline continues until 1973. From 1973 through

1984 the rates remain stable. The first period roughly coincides with the 50's decade. The three periods covering 1960 through 1972 are short and rather erratic making model selection quite difficult. The last period does not coincide with any previously studied decade and is long enough to model effectively. A model was fit including the lunar component but it was not statistically significant. The choice of data breakdowns does not seem to affect the significance of the lunar component.

III. Discussion

Several aspects of the data this study focused on may have made it intrinsically difficult to identify a lunar effect even if one does exist. Menaker and Menaker (1959) noted a large number of births (such as the 250,000 in their study) is needed to detect the magnitude of lunar effects on birth rates. This may explain why others with less data have found no lunar effect and illustrates some of the difficulties encountered in studying the lunar effect. Although having too few cases is not an issue in this study, there may be several other shortcomings with the data that prevent us from seeing a lunar effect in birth rates.

Phases of the moon are phenomena measured in days but our fertility data is compiled monthly. The higher level of aggregation may spread out any lunar effect to such a degree that it is impossible to detect . Most other studies dealt with daily data where it is much easier to associate individual observations with the corresponding full moon days. Another disadvantage of the data is due not to its aggregation over time but to its aggregation over geographic localities. Previous studies have examined data collected at one hospital or at most over an individual county. With such data it is possible to edit out cases that are not relevant to the study. To test for the presence of a full moon effect one would naturally want to consider only those live births where no human intervention occurred that would alter the course of nature (such as dispensing labor-inducing drugs or performing a cesarian section where the date of birth may be at the discretion of an attending physician). With national records of numbers of births only, there is no opportunity to identify and omit these cases. This contamination within the data would make it very difficult to detect a lunar effect. We attempted to account for the effects of these human interventions through the calendar variables in our models, but this effort was not entirely successful. The national monthly general fertility rate series is obviously not the ideal set of data with which to examine lunar effects.

The lack of evidence of a full moon effect in the monthly fertility rates does not necessarily imply that the effect is not present in daily birth data. Rather, we now know that there is no need to account for a lunar effect when we model the monthly fertility rates. We can be sure we are not ignoring a potential source of variation that may affect the fertility rates.

IV. Summary

We have attempted to simultaneously model and estimate a deterministic lunar effect in conjunction with a model for monthly general fertility rates that includes stochastic and deterministic components. Despite numerous approaches to parameterization of a lunar component, no significant effect was found. Several intrinsic shortcomings of the data may make detection extremely difficult anyway. Hence, there is no need to include a lunar effect in the model for the monthly fertility rates.

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Table 1. Results from 50's Decade and Window w_{22}

Model Description		$\hat{\delta}$	st. error	t	$\hat{\sigma}_e^2$
#TD	lunar effect				
7	birth	.0005	.0016	.34	$.157 \times 10^{-3}$
3	birth	.0007	.0016	.44	$.165 \times 10^{-3}$
2	birth	.0006	.0016	.36	$.165 \times 10^{-3}$
7	conception	-.0019	.0016	1.17	$.155 \times 10^{-3}$
3	conception	-.0013	.0016	.83	$.164 \times 10^{-3}$
2	conception	-.0014	.0016	.86	$.165 \times 10^{-3}$
7	crude conception	-.0028	.0015	1.93	$.132 \times 10^{-3}$
3	crude conception	-.0029	.0014	2.02	$.136 \times 10^{-3}$
2	crude conception	-.0029	.0014	2.01	$.136 \times 10^{-3}$

Table 2. Results from 50's Decade with 7 TD Variables and Various Windows

Model Description		$\hat{\delta}$	st. error	t	$\hat{\sigma}_e^2$
w	lunar effect				
w_{22}	birth	.0005	.0016	.34	$.157 \times 10^{-3}$
w_{42}	birth	.0011	.0012	.90	$.156 \times 10^{-3}$
w_{24}	birth	.0014	.0014	.96	$.156 \times 10^{-3}$
w_{44}	birth	.0012	.0012	1.00	$.156 \times 10^{-3}$
w_{11}	birth	.0008	.0023	.35	$.157 \times 10^{-3}$
w_{22}	conception	-.0019	.0016	1.17	$.155 \times 10^{-3}$
w_{42}	conception	-.0016	.0012	1.27	$.155 \times 10^{-3}$
w_{24}	conception	-.0014	.0016	.88	$.156 \times 10^{-3}$
w_{44}	conception	-.0013	.0012	1.06	$.156 \times 10^{-3}$
w_{11}	conception	-.0041	.0018	2.27	$.152 \times 10^{-3}$
w_{22}	crude conception	-.0028	.0015	1.93	$.132 \times 10^{-3}$
w_{42}	crude conception	-.0018	.0011	.97	$.133 \times 10^{-3}$
w_{24}	crude conception	-.0006	.0014	.42	$.136 \times 10^{-3}$
w_{44}	crude conception	-.0006	.0011	.54	$.135 \times 10^{-3}$
w_{11}	crude conception	-.0013	.0023	.58	$.140 \times 10^{-3}$

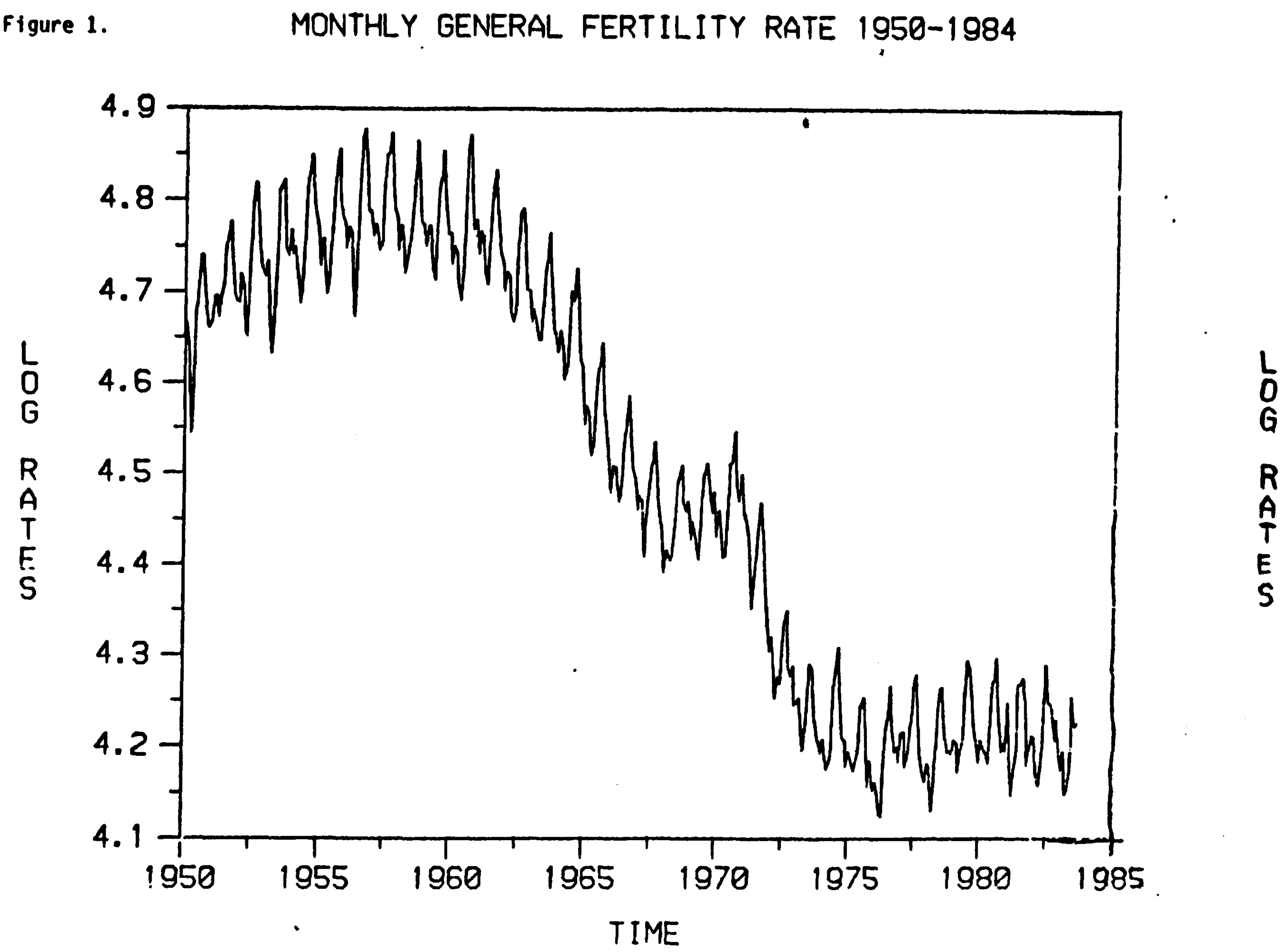
Table 3. Results from 60's Decade with 2 TD Variables

Model Description		$\hat{\delta}$	st. error	t	$\hat{\sigma}_e^2$
w	lunar effect				
w_{22}	birth	-.0002	.0014	.16	$.125 \times 10^{-3}$
w_{11}	birth	-.0022	.0016	1.37	$.123 \times 10^{-3}$
w_{22}	conception	-.0006	.0012	.47	$.124 \times 10^{-3}$
w_{11}	conception	-.0008	.0016	.52	$.124 \times 10^{-3}$
w_{22}	crude conception	.0009	.0014	.65	$.116 \times 10^{-3}$
w_{11}	crude conception	.0004	.0018	.20	$.117 \times 10^{-3}$

Results from 70's Decade with 2 TD Variables

Model Description		$\hat{\delta}$	st. error	t	$\hat{\sigma}_e^2$
w	lunar effect				
w_{22}	birth	.0003	.0022	.14	$.148 \times 10^{-3}$
w_{11}	birth	-.0004	.0034	.11	$.148 \times 10^{-3}$
w_{22}	conception	-.0007	.0021	.31	$.148 \times 10^{-3}$
w_{11}	conception	-.0006	.0032	.19	$.148 \times 10^{-3}$
w_{22}	crude conception	.0029	.0023	1.23	$.144 \times 10^{-3}$
w_{11}	crude conception	.0015	.0035	.44	$.146 \times 10^{-3}$

Figure 1.



MONTHLY GENERAL FERTILITY RATE 1950-1984
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
LOG RATES
1950
1955
1960
1965
1970
1975
1980
1985
TIME
LOG RATES