LOG-LINEAR ANALYSIS OF FERTILITY USING CENSUS AND SURVEY DATA WITH AN EXAMPLE

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The use of log-linear models is relatively new to the field of demography, especially in the analysis of fertility. Previous log-linear analyses have been largely studies of cohort mobility and of infant mortality [8]. This paper shows the value in fitting multiway tables when analyzing fertility with census and survey data. An example of differential current fertility using a 20% sample of the census of Costa Rica will be presented. The variables were all discrete and categorical which made the log-linear approach an appropriate technique. In addition, with this method we had the potential of creating as detailed a contingency table as was necessary and could evaluate the complicated interaction terms in a simple, systematic, and statistically robust manner.

Often research in fertility presents findings in the form of tables. Two and three way tables have often been used but the construction of higher than three-way tables becomes difficult to synthesize and unwieldy to present in tabular form. This type of analysis misses a great deal concerning the factors influencing fertility. Even if chi-square statistics are calculated for the respective tables it is usually difficult to identify a unifying strain within many multiway tables. Also, without a systematic method of constructing tables to include patterns of interactions between variables, there can be little comparability between them.

One method of getting around this has been linear regression. Historically fertility analysis has dealt with aggregate measures or small samples and was thus appropriate for regression analysis. Individual level analysis for large samples has generally not been possible as data has been unreliable or incomplete on the individual level. Adding interaction terms to regression models is possible using dummy variables but, unlike log-linear models, there is no simple way to identify and test the interaction terms in the model. While any combination of variables can be input in a log-linear model with one term, many terms are required for interactions in dummy variable regression.

Again, returning to aggregate level analysis, another often used method is the construction of various fertility rates for comparison within a crosstabulation by the variable of interest. While this gives good comparisons within variables it becomes a cumbersome procedure as the categories of the variables and the dimensions of the table increase. It provides no overall measure of the significance within and between these rates, so conclusions based on these rates alone may be tenuous. Also, the rates for a country may differ greatly from those of smaller areas within the country or with the individual.

There are several applications of log linear models, not all are of interest here. For example, one may wish to examine the fitted table as well as the Likelihood Ratio Statistic. However, in this paper we are more interested in how well the model fits the table, reflected in the goodness of fit statistics and in the fitted parameters of the model. Rather than simply finding the table's best fit we are interested in a dependent variable approach. In our approach we are interested in identifying the factors that effect the distribution of the dependent variables within each cell, and the direction and strength of those factors, rather than factors that effect the number of cases in each cell. It has been shown by Goodman [9] that when analyzing a contingency table using a dependent variable approach only those terms involving the dependent variable need be included as all other terms will cancel.

Therefore, we are concerned with sampling from a Multinomial distribution where the population being studied can fall into one and only one of t categories with a probability p_i where (p_i) is the vector of cell probabilities summing to one for the t categories [5]. The p_i reflect the relative frequency of each category in the population. A structure may be imposed when using two or more variables or dimensions, the data are usually represented as groups of rectangular arrays. This structure can be described by models linear in the logarithmic scale. The term model used here is analogous to the equation of linear regression; its parameters, additive and multiplicative effects, are similar to metric beta coefficients and their significance, and the significance of the whole model is measured by the magnitude, or goodness of fit, of the Likelihood Ratio Statistic. The lack of fit of the model may be compared to the magnitude of the error sum of squares in regression or inversely to the multiple-R^2.

We are interested in the amount of reduction in the Likelihood Ratio Statistic occurring between two models, which gives an indication of the importance of adding an additional term to the model. The statistic reported in fitting a multiway table gives an indication of the fit of the entire model to the observed data while the difference between statistics indicates the importance of individual terms. The models fit in this paper are hierarchical models. High order terms may only be included in the model if the related low order terms are included [9]. In assessing the significance of any particular term or interaction to the model several measures of

association are available. The two measures used for testing particular terms in this paper were marginal and partial association [10]. These show the effect of adding a higher order term to the saturated model of next lowest order and the effect of dropping a term from the model of a certain order, respectively.

Two 10% samples of the 1973 census of Costa Rica were available, these were non-overlapping systematic samples of families and were combined for the purposes of this work. From this sample, a file was created for each woman over 15. Using methods similar to those developed by Lee-Jay Cho and others of the East-West Center the number and ages of own children were estimated for these women. Own children are children present in the family who cannot be shown not to be a woman's children [3]. The relative ages of the woman and child and the number of surviving children a woman had were used as criteria in this process. If she had more children present than surviving the oldest children were assumed not to be own children [3]. Women 50 and older who were not likely to have had children in the five years before the census, the widowed and divorced, and women under 20 were excluded from the sample, yielding 87,540 cases.

Two models were fit, the first used the number of children born to each woman in the five years before the census as its dependent variable. From other analysis it can be shown that this variable gives a good approximation of period fertility rates in Costa Rica on an overall basis. A second model used a dichotomized version of this variable, dividing women into those who did or did not have children in the five year period. The use of two models allowed a thorough examination of the information that was lost in this dichotomization.

The independent variables were: Age, in five year age groups; Marital Status, Single, Married or Consensual Union; Urban /Rural; Education, None, Primary and Secondary or more; Working/Not Working. Since the complete fertility histories were available through the use of the own children method we could develop a control variable based on the woman's fertiltiy history at the beginning of the five year period in question. Five categories of previous fertility were delineated ranging from those with no previous children to those with eight or more children. The inclusion of this variable as a control had two purposes: It allows us to distinguish timing patterns as we are, in effect, explaining the change in fertility from one period to the next and it also gives an indication of the variables not included in the model by how important a part it plays in determining differential fertility.

Results

Tables 1, 2, and 3 give the detailed results of fitting the models. The L.R.S. of fitting both models is given in Table 1. Though both fit well the model with six categories of fertility was slightly better. A small, and not significant L. R.S. indicates a small difference between the observed and expected values and is desireable for a well fitting model. Both models include only those term of the third order with age or previous fertility controlled. For example the interaction of Urban/Rural, Age and Current Fertility and the interaction of Urban/Rural, Previous Fertility and Current Fertility were included. Each term was tested and marginal and partial association were both significant. The possibly confounding effect of the interactions between independent variables has been controlled for by including the six-way interaction of all the independent variables.

Tables 2 and 3 present the multiplicative parameters of the model, first with dichotomous current fertility and next with the full six categories. In Table 2 the second order effects appear across the top of the table and in the right-most column. These are the interactions of Current Fertility and each independent variable. The body of the table contains the third-order effects, or the indirect effects; interactions of Current Fertility and each independent variable controlled for Age or Previous Fertility. In Table 3 the second order effects are in 3a and the third order effects controlling for Age and Previous Fertility are in 3b and 3c respectively. The multiplicative parameters for the dichotomous dependent variable are reciprocals of one another and for both models these parameters are constrained to multiply to 1 within any category. It is the parameters' difference from 1 which determines how great an effect it is having on the dependent variable. In examining Table 2, for example, the second order effect for Urban/Rural is .788 on experiencing current fertility and 1.268 for no fertility. This variable has a fairly strong effect on Current Fertility here but when the effect of Age is controlled, in 2, the third order Urban/Rural multiplicative effects are close to 1.

From these tables we see that fertility in rural Costa Rica, and for women in Consensual Unions, is higher than that of urban areas or women who are married, especially in younger age groups. The more education a woman has, or if she is working, the fewer children she has. The differential is greatest at younger ages and reverses at the higher ages perhaps showing that these women have merely postponed childbearing while working or going to school or perhaps because of their higher social status.

Although the results of fitting the models are complex, a significant pattern emerges: for social and economic variables the differentials decrease with age. This

is the opposite of what would be expected with the demographic transition which supposes that the differentials in fertility depend on the age at which women cease childbearing. The patterns of three way interactions for Previous Fertility are, in a sense, reversed from those by age, the zero parity women have the smallest differentials by Education and Urban/ Rural while the high parity women have strong interactions. This is as expected by the theory of demographic transition. Childlessness is a function of exogenous factors such as sterility while, the parity at which women stop childbearing is expected to be affected by her social class.

The log-linear model with six categories of current fertility has the effect of taking the women who had experienced fertility in the last five years and further dividing them by fertility. While we found distinct advantages to the dichotomized variable, among them the ease of presentation of one number for each category of each independent variable and the ability to easily calculate the total odds ratios of experiencing current fertility from tables and , information about the details of the distribution of current fertility is lost using this variable. Particularly the curvilinear effect of some of the variables on current fertility was not evident when the variable was dichotomized.

In Table 3 patterns can be seen by looking down the categories of current fertility. The overall effect of Urban women experiencing fertility was negative in Table 2 but it is positive for current fertility of one child and highly negative thereafter. So it is large numbers of women having small families and perhaps a family planning mechanism at work. Also, in Table 2, the large positive effects for current fertility 5+ controlled for age and previous fertility reflect a small number of cases in the whole sample. So while the odds of a woman in these categories experiencing high current fertility are great, there are very few women in these categories.

Another relationship exhibited in the six category model is the curvilinear one. Both the single women, those women who are working, and the highly educated are most likely to have no children or a great many children as can be seen in Table 3. For single women, those with many children may be from low status groups or widowed or separated from consensual unions. In the case of the highly educated or working, these are probabily high status women.

The construction of graphs of the multiplicative parameters can be useful for polytomous dependent variables. These can show the spread of the differentials and how they change when controlled by a third variable.

When analyzing fertility in this manner an estimate of a woman's average fertility can be constructed using the odds ratios. After construction of the odds ratio for a certain set of independent variable categories these categories can be converted into probabilities by the relationship

$$P = \frac{Odds}{1 + Odds}$$

and standardized for the number and value of the categories. After multiplying the probability by the current fertility category it is summed and averaged to give the average fertility. For example for Age (20-24); Urban; Single; Not Working; Education (Primary); with no Previous Fertility the probabilities for each category of Current Fertility are as follows:

0 : .8321
1 : .1364
2 : .0305
3 : .0028
4 : .0002
5+: .00003

So the average fertility experienced by a woman in this category for the last five years would be: 0(.8321) + 1(.1364) + 2(.0305) + 3(.0028) + 4(.0002) + 5.3(.00003) = .200.

Conclusions

As we have shown, there are a variety of techniques for presentation of the results of fitting a log-linear model which are meaningful to the demographer: Tables of second and third order effects reflecting linear and curvilinear trends, graphs illustrating the comparison of the differential effects of different variables on fertility before and after controlling for age and previous fertility. the construction of odds ratios and manipulating them to find the probability of being in a certain category of current fertility and finally, taking the product of these probabilities by their fertility category and averaging them to find a measure of average fertility for women in a certain group of independent variable categories.

Log-linear analysis seems especially appropriate for census and survey data for several reasons: The size of the data set can by quite large and the use of regression techniques, especially in evaluating the significance of coefficients, is difficult; The content of the variables is often categorical; The construction and evaluation of interaction is simple and straightforward in log-linear analysis; The alternative to fitting the model, the examination of high order contingency tables, give no significance of interactions or overall fit.

Since so many demographic analyses begin, and sometimes end, with the construction of multiway tables the implementation of a log-linear model is an easy and appropriate step forward from the present methods. Its greatest advantages are in allowing for the determination

and inclusion of interactions of independent and dependent variables and in summarizing what might otherwise by a contingency table of unmanageable size.

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Table 1: Likelihood Ratio Statistics for Second and Third Order Models Controlled For Age and Previous Fertility.

Dichotomous Current Fertility:

	L.R.S.	d.f.
All second order	8274.38**	1693
Controlled for Age	6740.57**	1245
Controlled for Prev.Fer.	5632.47**	1545
Controlled for both	1016.04*	821

Six Categories of Current Fertility:

All Second Order	12880.20**	5233
Controlled for Age	8590.63**	4637
Controlled for Prev.Fer.	7603.91**	4637
Controlled for Both	2646.97	4105

** .001 level of significance
* .1 level of significance

Table 2. Dichotomous Current Fertility* Controlled for Age

Age of Woman	20-24	25-29	30-34	35-39	40-44	First Order Current Fert. Tau	Prev. Fert. 0	1	2-4	5-7	8+	First Order Curr. Fert. Tau^2
Second Order Tau^2	1.915	1.646	1.367	.780	.498	.978	.490	1.057	1.281	1.203	1.257	.978

Table 2: Dichotomous Current Fertility* Controlled for Previous Fertility

Third Order Tau^2 Interactions Curr. Fert./Age						Second Order Tau^2	Third Order Tau^2 Interactions Current Fertility/Prev. Fertility					Second Order Tau^2
Urban/Rural	U	.953	1.000	1.036	.994	1.022	.788	Urban/Rural	U	1.371	1.052	.882	.897	.876	.788
	R	1.050	1.000	.965	1.006	.978	1.268		R	.729	.950	1.134	1.115	1.141	1.268
Marital Status	S	.885	.939	.982	1.073	1.138	.457	Marital Status	Single	.340	.869	1.423	1.662	1.435	.457
	M	.819	1.036	1.138	1.026	1.008	1.428		Married	2.193	1.270	.738	.635	.764	1.428
	C.U.	1.376	1.028	.895	.908	.872	1.533		Cons. Union	1.341	.906	.953	.946	.912	1.533
Labor Force Status	Non. W.	1.162	1.192	.976	.885	.837	1.237	Labor Force Status	Not W.	.859	1.012	.984	1.089	1.057	1.237
	W.	.861	.819	1.024	1.129	1.194	.809		Working	1.164	.988	1.016	.902	.946	.809
Education	None	1.230	1.1025	.945	.982	.796	.972	Education	None	.837	.846	1.086	1.158	1.119	.972
	Prim.	1.293	1.012	.924	.878	.945	.958		Primary	1.049	.941	.933	1.105	.984	.958
	Sec.+	.629	.897	1.147	1.160	1.332	1.073		Secondary+	1.138	1.254	.988	.781	.908	1.073
Prev. Fert.	0	1.278	1.381	1.002	.711	.774	.490	Age	20-24	1.277	1.646	1.638	.679	.468	1.915
	1	1.646	1.376	.939	.792	.594	1.057		25-29	1.381	1.376	1.096	.974	.493	1.646
	2-4	1.634	1.096	.805	.880	.789	1.281		30-34	1.002	.939	.803	1.008	1.313	1.367
	5-7	.679	.974	1.008	1.234	1.214	1.203		35-39	.733	.794	.880	1.234	1.654	.780
	8+	.428	.493	1.313	1.593	2.271	1.257		40-44	.774	.594	.789	1.214	2.25	.298

*the numbers in the table reflect the odds of experiencing current fertility, the odds of experiencing no fertility are the reciprocals of these numbers.

Table 3 : Current Fertility with Six Categories

Current Fertility		0	1	2	3	4	5+
First Order Tau		12.138	4.752	1.737	.476	.190	.110
Second Order Tau Effects							
Urban/Rural	Urban	1.700	1.320	.891	.677	.796	.927
	Rural	.588	.757	1.122	1.476	1.257	1.079
Marital Status	Single	2.846	.848	.554	.529	.943	1.501
	Married	.910	1.698	1.682	1.369	.723	.389
	Cons. Union	.386	.694	1.073	1.383	1.467	1.711
Labor Force Status	Not Working	.901	1.141	1.570	1.325	.834	.563
	Working	1.110	.877	.637	.755	1.200	1.780
Education	None	.458	.601	.876	1.281	1.766	1.833
	Primary	1.503	1.600	1.362	1.223	.663	.377
	Secondary+	1.450	1.040	.839	.638	.854	1.450
Prev. Fert.	0	4.951	1.173	.947	.701	.537	.482
	1	1.090	1.171	1.008	1.057	.867	.850
	2-4	1.318	1.682	1.311	.826	.587	.709
	5-7	.536	.790	.880	1.084	1.605	1.543
	8+	.262	.548	.908	1.508	2.277	2.232
Age	20-24	.213	.738	1.304	1.748	1.750	1.595
	25-29	.482	1.103	1.418	1.316	1.016	.992
	30-34	.893	1.295	1.462	.841	.863	.811
	35-39	1.902	1.195	.857	.814	.815	.773
	40-44	5.717	.801	.432	.634	.799	1.008

Table 3a: Six Categories of Current Fertility

Third Order Tau Effects Controlled for Age						
Age Group		20-24	25-29	30-34	35-39	40-44
Current Fertility						
Urban:	0	1.032	.970	.939	1.057	1.010
	1	.990	1.026	1.036	1.026	.927
	2	1.069	1.062	1.018	.933	.927
	3	1.004	1.145	.943	.939	.984
	4	.994	.978	.962	.990	1.080
	5+	.918	.846	1.113	1 064	1.085
Marital Status:						
Single:	0	1.621	1.280	1.054	.752	.588
	1	1.243	1.156	1.239	.808	.696
	2	1.355	1.117	.848	1.022	.762
	3	1.201	.843	.731	.908	1.489
	4	.557	.895	.955	1.281	1.644
	5+	.549	.805	1.248	1.383	1.309
Married:	0	.889	.743	.824	1.219	1.510
	1	.679	.803	1.004	1.237	1.484
	2	.630	.863	1.234	1.237	1.206
	3	.884	1.221	1.237	1.032	.728
	4	1.823	1.171	.922	.753	.676
	5+	1.636	1.364	.859	.691	.755
Consensual Union:	0	.696	1.055	1.111	1.092	1.126
	1	1.186	1.080	.805	1.002	.968
	2	1.173	1.038	.955	.792	1.088
	3	.728	.974	1.105	1.067	.925
	4	.986	.955	1.136	1.036	.901
	5+	1.113	.910	.933	1.047	1.012
Labor Force Status:**	0	.699	.740	.978	1.219	1.623
	1	.845	.956	.914	1.049	1.295
	2	1.113	1.100	.904	.929	.972
	3	1.156	1.186	1.145	.914	.697
	4	1.223	1.259	1.012	.874	.736
	5+	1.080	.861	1.069	1.055	.955
Education: None:	0	.687	.790	1.057	1.069	1.631
	1	.759	.887	.945	1.160	1.355
	2	1.272	.785	.889	1.059	1.063
	3	1.107	1.201	.976	.966	.797
	4	1.435	1.055	.988	.988	.764
	5+	1.075	1.435	1.164	.797	.699

*Tau effects for Rural are the reciprocals of those for Urban

** Tau effects for Working are the reciprocals of those for Not Working.

Table 3a (continued)

Age Group		20-24	25-29	30-34	35-39	40-44
Primary:	0	.529	.837	1.130	1.364	1.469
	1	.861	.841	1.026	1.042	1.290
	2	1.042	.972	.893	1.006	1.100
	3	1.362	.876	1.033	1.115	.728
	4	1.266	1.452	1.067	.748	.682
	5+	1.223	1.149	.876	.839	.968
Secondary+:	0	2.752	1.512	.837	.686	.419
	1	1.532	1.341	1.030	.826	.572
	2	.755	1.311	1.259	.939	.856
	3	.664	.949	.992	.927	1.724
	4	.623	.653	.949	1.354	1.918
	5+	.760	.607	.980	1.496	1.473
Previous Fertility	0	3.602	1.111	.805	.706	.440
	1	4.718	1.823	.903	.407	.317
	2	2.443	1.669	.834	.587	.500
	3	.714	1.203	1.115	.970	1.077
	4	.386	.517	.920	1.785	3.049
	5+	.088	.475	1.613	3.426	4.364
1:	0	.960	1.010	1.171	.904	.916
	1	1.362	1.742	1.430	.750	.394
	2	1.538	1.651	1.098	.697	.514
	3	1.358	1.173	.734	.850	.984
	4	.699	.697	.712	1.348	2.140
	5+	.514	.421	1.038	1.737	2.560
2-4:	0	.475	.856	1.237	1.374	1.450
	1	.707	.889	1.042	1.416	1.077
	2	1.062	1.092	1.022	1.169	.724
	3	1.049	1.421	.935	.764	.880
	4	1.223	1.024	1.057	.880	.859
	5+	2.187	.826	.771	.656	1.096
5-7:	0	.486	.990	1.069	1.190	1.633
	1	.374	.796	.870	1.685	2.289
	2	.531	.659	1.126	1.550	1.636
	3	1.243	.933	1.016	1.212	.701
	4	2.100	1.166	1.245	.701	.468
	5+	3.956	1.772	.755	.379	.500
8+:	0	1.254	1.051	.805	.901	1.049
	1	.587	.445	.856	1.376	3.251
	2	.471	.506	.949	1.350	3.283
	3	.776	.534	1.286	1.311	1.433
	4	1.445	2.323	1.162	.674	.381
	5+	2.576	3.415	1.026	.676	.164

*Tau effects for Rural are the reciprocals of those for Urban

** Tau effects for Working are the reciprocals of those for Not Working.

Table 3b Six Categories of Current Fertility

Third Order Tau Effects Controlled for Previous Fertility

Previous Fertility Group:		0	1	2-4	5-7	8+
Current Fertility						
Urban:*	0	.686	1.000	1.932	1.084	.968
	1	1.105	1.077	1.130	.972	.766
	2	1.230	1.128	1.028	.755	.927
	3	1.177	.962	.953	1.032	.867
	4	1.002	.921	.834	1.080	1.203
	5+	.910	.929	.778	1.130	1.348
Marital Status:						
Single:	0	8.952	1.484	.551	.361	.379
	1	1.197	1.194	.958	.893	.817
	2	.640	.845	1.286	1.325	1.086
	3	.494	.908	1.259	1.385	1.279
	4	.508	.951	1.096	1.208	1.563
	5+	.582	.774	1.071	1.395	1.486
Married:	0	.274	.769	1.667	2.019	1.409
	1	1.169	1.212	1.042	.861	.785
	2	1.623	1.189	.771	.741	.908
	3	1.583	1.047	.760	.878	.904
	4	1.177	.815	1.067	.859	1.138
	5+	1.034	1.059	.922	1.028	.966
Consensual Union:	0	.048	.876	1.089	1.371	1.871
	1	.716	.691	1.002	1.300	1.558
	2	.964	.998	1.010	1.018	1.014
	3	1.281	1.053	1.046	.821	.863
	4	1.671	1.293	.854	.964	.563
	5+	1.662	1.221	1.014	.697	.697
Labor Force Status:**	0	1.115	.956	.992	.920	1.028
	1	.887	1.071	.996	1.024	1.032
	2	.897	.939	.968	1.098	1.117
	3	.943	.933	1.030	1.049	1.053
	4	1.179	1.069	1.077	.958	.769
	5+	1.014	1.042	.941	.964	1.042
Education:						
None	0	.879	.964	.760	1.049	1.479
	1	.751	.908	.750	1.203	1.623
	2	.632	.774	1.184	1.279	1.346
	3	.899	.897	1.026	1.128	1.073
	4	1.360	1.210	1.186	.835	.613
	5+	1.957	1.357	1.217	.658	.417
Primary:	0	.931	1.164	1.014	.908	1.004
	1	1.053	.878	.925	1.184	.990
	2	.954	.984	1.006	1.075	.984
	3	1.087	1.006	1.151	1.036	.766
	4	1.121	1.094	1.012	.796	1.012
	5+	.878	.904	.910	1.051	1.318
Secondary+:	0	1.221	.891	1.297	1.051	.674
	1	1.263	1.254	1.440	.702	.623
	2	1.656	1.311	.839	.728	.755
	3	1.024	1.109	.846	.857	1.217
	4	.656	.755	.834	1.503	1.613
	5+	.582	.815	.904	1.447	1.613

* Tau effects for Rural are the reciprocals of those for Urban.

**Tau effects for Working are the reciprocals of those for Not Working.