International Journal of AI & Data Science
Review Volume1, Issue 4, 2025

Analyzing Collinear Data by Principal Component Regression Approach — An Example from Developing Countries

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Article Info

Received: 23-07-2025 Revised:21-08-2025 Accepted:23-10-2025 Published:07-11-2025

Abstract: This research uses national level data from 43 developing countries to determine the impact of family planning program effort and socioeconomic variables on the overall fertility rate. The majority of the information utilized came from the secondary source "Family Planning and Child Survival: 100 Developing Countries," which was put together by Columbia University's Center for Population and Family Health.
The data was analyzed using the component regression approach as it was discovered that the independent variables were significantly connected with one another. According to the research, the family planning program has had the most impact to reducing the overall fertility rate. This is followed in order by the percentage of the population living in cities, the rate of female literacy, and the infant mortality rate. Implications for policy are examined.

Key words: Family planning program, principal component regression, total fertility rate.

Introduction

Rapid population increase is one of the biggest issues facing many emerging nations. Despite evidence of declining fertility in many developing nations from the World Fertility Survey and the Con-traceptive Prevalence Surveys, women in these nations continued to have large families with significant fertility, and there were differences in the use of contraceptives between nations (Population Reports, 1985). The idea that family planning programs primarily contributed to the recent decline in fertility in some developing nations may give rise to the notion that the socialization of family planning services could reduce the fertility gap between developing and developed nations. Fertility is indeed severely harmed by family planning programs (Poston and Baochang, 1987; Cutright and Kelly, 1981; Mauldin and Berelson, 1978; Tsui and Bogue, 1978; Caldwell et al., 2002). However, as the socioeconomic development of the emerging nations varies greatly, it's possible that the countries with significant socioeconomic progress had the biggest declines in fertility.
Numerous studies have shown how socioeconomic factors affect fertility. By raising the age of marriage and the probability of using contraceptives, education reduces fertility (Casteline et al., 1984; Diamond et al., 1997). Similar negative effects of schooling on fertility were also noted by other researches (Entwisle and Mason, 1985; Rubin-Kurtzman, 1987; Jiang, 1986; Krishnan, 1988; Prada and Ojeda, 1986; Shapiro and Tambashe, 1994; Kravdal, 2002). Fertility has also been shown to be strongly correlated with place of residence: rural women had higher overall fertility rates than urban women (Alam and Casterline, 1984; Rubin-Kurtzman, 1987; Prada and Ojeda, 1986). Fertility and income have a negative relationship (Rubin-Kurtzman, 1987; Jiang, 1986).
The fact that fertility, socioeconomic development, and family planning practices vary greatly among developing nations is a key factor in the analysis of fertility in these nations. Furthermore, many developing nations have access to the relevant data. This study was driven by the central issue of whether and to what degree variations in national fertility levels are caused by socioeconomic and other developmental variables, as well as how these impacts differ from those caused by family planning programs. The reasoning for this is because, after the impact of family planning programs is eliminated, socioeconomic and other developmental variables do have both independent and combined effects on the

fertility rate. This research aims to investigate these determinants and their respective contributions to the differences in fertility levels among many developing nations for which relevant statistics are available. The study's significance stems from the need to pinpoint the demographic groups whose excessive fertility may be decreased by altering governmental regulations and reallocating resources.

Data and Methods Data and Variables

The fertility statistics of forty-three developing nations in Asia, Africa, and Latin America were examined in this study. The information came from the 1987 World Population Data Sheet (Population Reference Bureau, 1987) and Family Planning and Child Survival: 100 Developing Countries (Ross et al., 1988), which was put together by the Center for Population and Family Health, Columbia University, New York. The appendix displays the data.

The total fertility rate (TFR: Y), which is the number of live births a hypothetical woman would have if she lived to the

experienced a distinct set of age-specific fertility rates at the conclusion of her reproductive cycle. Explanatory factors are those that have been shown to be important in explaining fertility variance in past research. These variables include the following: the percentage of the population that lives in urban areas (URBAN: X1), the percentage of the population that has access to a safe water supply (SWATER: X2), the percentage of the population per square kilometer (DENSITY: X3), the percentage of women aged 15 and older who are literate (FLITERACY: X5), the family planning program effort score based on four components: policy and stage setting, service, record keeping and evaluation, availability and accessibility (FPSCORE: X6), the infant mortality rate, or the number of infant deaths per thousand live births (IMR: X7), the per capita energy use (ENERGY: X8), and the gross national product (GNP: X9). These factors were covered in further depth by Ross et al. (1988) and the Population Reference Bureau (1987). 43 developing nations with data available for each of the ten factors served as the basis for the investigation.

Table 1: Means and standard deviations of total fertility rate, and nine explanatory variables: 43 developing countries from Asia, Africa, and Latin America.

Variable	Mean	Standard Deviation
TFR: Y	5.449	1.545
URBAN: X_1	37.651	16.743
SWATER: X_2	50.721	22.479
DENSITY: X_3	160.849	404.902
CALORIE: X_4	2352.279	385.770
FLITERACY: X_5	53.395	26.123
FPSCORE: X_6	38.014	25.862
IMR: X_7	87.472	37.963
ENERGY: X_8	13.140	22.753
GNP: X_9	831.395	916.150

Table 1 presents the means and standard deviations of the dependent, as well as, of the explanatory variables. The TFR has an average value of 5.5 children per woman varying from lows of 2.3 children in Mauritius, and 2.4 children in Chile to highs of 8.5 children in Rwanda, and 8.0 children in Kenya. We expect negative re-lationships between TFR and the variables $URBAN,\ SW\ AT\ ER,\ CALORIE,\ FL\ ITERACY,\ FPSCORE,\ ENERGY$, and GNP, while we hypothesize positive relationships between TFR and the variables IMR, and $DENSITY$. The results

of fitting the ordinary least squares (OLS) regression model

$$Y = \gamma_0 + \sum_{i=1} \gamma_i X_i + U \qquad 9$$

(where γ_0 is the intercept, and γ_i's are the regression coefficients) connecting the total fertility rate Y and the nine

explanatory variables $X_1, X_2, \ldots, X_9$ are shown in table 2.
The F value is significant at probability level 0.0001, implying that the vari-ables chosen are valid explanatory variables (Chatterjee and Price, 1977, p.146). The table shows that the value of R^2 is quite large (0.72). This does not, how-ever, imply a good fit (Anscombe, 1973), nor that the model assumptions have not been violated (Chatterjee and Price, 1977). Plots of the standardized resid-uals against the fitted values, as well as, against the explanatory variables did not show any systematic pattern of variation, and all the standardized residuals fell between +2 and −2. Neither did they detect the presence of any outliers. Consequently, there is no evidence for model misspecification, nor for any serious violations of model assumptions.

Table 2: Unstandardized and standardized coefficients of regression of total fertility rate on the nine explanatory variables.

Variable	Unstandardized Coefficients	T Value	$Pr > T$ Coefficients	Standardized
INTERCEPT	7.8210	4.41	0.0001	0
URBAN: X_1	−0.0312	−2.86	0.0073	−0.3378
SWATER: X_2	0.0057	0.57	0.5719	0.0824
DENSITY: X_3	−0.0004	−0.97	0.3386	−0.0973
CALORIE: X_4	0.0001	0.25	0.8029	0.0323
FLITERACY: X_5	−0.0119	−1.35	0.1864	−0.2008
FPSCORE: X_6	−0.0333	−4.56	0.0001	−0.5569
IMR: X_7	0.0038	0.51	0.6106	0.0927
ENERGY: X_8	−0.0009	−0.04	0.9714	−0.0128
GNP: X_9	−0.0002	−0.28	0.7834	−0.1070

$N = 43,\ R^2 = 0.7214,\ S = 0.9200$
Having specified the model properly, we need to see whether multicollinearity could be a problem. Among the nine explanatory variables, two variables — $ENERGY$ and GNP — are strongly correlated ($r = 0.95$). Each explanatory variable was then regressed on all other explanatory variables. Two of the eight possible R^2's from such regressions — R^2's from regressions of $ENERGY$ and GNP — were quite large (0.93 and 0.94 respectively). The eigen values of the correlation matrix of the explanatory variables have also been calculated. The smallest of these eigen values is 0.031 which is quite small, and can be taken to be close to zero. The sum of the raciprocals of these eigen values is 48.06 which is greater than five times the number of explanatory variables used. All these indicate the presence of multicollinearity in the data, and as such, the estimates of the model parameters obtained by the OLS regression method are unstable and unreliable. To avoid this problem, we have used an alternative method of estimation - principal component regression (PCR) - which is recommended when multicollinearity is present in the data (Chatterjee and Price, 1977 :175). The PCR method produces estimates which, although biased, have smaller mean square error compared to the estimates provided by the OLS method.

The nine possible eigen values of the matrix of bivariate correlations between pairs of the explanatory variables in descending order are:
$\lambda_1 = 4.30714,\ \lambda_2 = 1.38838,\ \lambda_3 = 1.12067,$
$\lambda_4 = 0.68244,\ \lambda_5 = 0.55685,\ \lambda_6 = 0.37898,$
$\lambda_7 = 0.32980,\ \lambda_8 = 0.20487,$ and $\lambda_9 = 0.03086,$
and the corresponding eigen vectors (written as row vectors) are:
$' = (c_{1j}, c_{2j}, \ldots, c_{9j}),$
$j = 1, 2, \ldots, 9$. The nine principal components $Z_1, Z_2, \ldots, Z_9$ are given by

$$Z_j = \sum_{i=1}^{9} c_{ij} X_i, \qquad j = 1, 2, \ldots, 9 \quad (9)$$

which are linear functions of the standardized explanatory variables with the covariance matrixwhere the α's and β''s are related as

$$\alpha_j = \sum_{i=1}^{9} c_{ij}\beta', \quad j = 1, 2, \ldots, 9 \qquad (2.4)$$

$$\beta'_j = \sum_{i=1}^{9} c_{ji}\alpha_i, \; j = 1, 2, \ldots, 9. \qquad (2.5)$$

The variance of Z_9 is $\lambda_9 = 0.03086$ which is small and, as mentioned before, can be taken to be approximately zero. This implies that the variable Z_9 is approximately constant, and hence is equal to its mean. Since Z_9 is a linear function of standardized variables x_i, Z_9 has a mean zero. It follows that the variable Z_9 is itself approximately zero and is the source of multicollinearity. Let us exclude Z_9 and regress y on $Z_1, Z_2, \ldots, Z_8$. The possible regressions to be considered are

$$y = \sum_{i=1}^{k} \alpha_i Z_i + U, \qquad k = 1, 2, \ldots, 8 \quad (2.6)$$

Each of these models will lead to estimates of all nine of the original coefficients $\beta'_i, i = 1, 2, \ldots, 9$. These estimates will be biased since Z_9 has been excluded in all cases. The inclusion of Z_9 would produce exactly the same estimates as were obtained by using the OLS regression of Y on all the nine explanatory variables given in table 2. It is to be noted that the regression coefficients in (2.6) can be obtained in a simpler way by exploiting the orthogonality property of $Z_1, Z_2, \ldots, Z_9$ without actually performing the regressions. Because of this orthogonality property, α_1 is the same for all $k = 1, 2, \ldots, 8$. Similarly, α_2 is the same for all $k = 1, 2, \ldots, 8$. The same is true for other α's. Then using the standardized estimates, denoted
's, based on all the nine principal components (column 18 of table 3 which
is the same as the last column of table 2), we can obtain the estimates of the α's by using the equations (2.4). In order to obtain principal component regressionestimates of the β''s corresponding to equations in (2.6) we can refer back to equations (2.5) and set the appropriate α's to zero. Using the standardized estimates β' 's from the last column of table 3 in equations (2.4), we have the
corresponding estimates of α's as

$\alpha_1 = -0.3160, \alpha_2 = -0.3229, \alpha_3 = 0.2299$
$\alpha_4 = -0.0724, \alpha_5 = 0.1336, \alpha_6 = -0.2200$
$\alpha_7 = -0.4091, \alpha_8 = -0.0160, \alpha_9 = -0.0775.$

Setting $\alpha_1 = -0.3160$, and $\alpha_2 = \alpha_3 = \cdots = \alpha_9 = 0$ in equations (2.5) we get estimated β''s corresponding to the regression on the first principal component only. The estimated β''s corresponding to the first two principal components are obtained by setting $\alpha_1 = -0.3160, \alpha_2 = -0.3229$, and $\alpha_3 = \alpha_4 = \ldots = \alpha_9 = 0$, and those corresponding to first three principal components are obtained by setting $\alpha_1 = -0.3160, \alpha_2 = -0.3229, \alpha_3 = 0.2300$, and $\alpha_4 = \alpha_5 = \cdots = \alpha_9 = 0$. The estimates of β''s corresponding to other regressions are obtained in a similar way. The results of all these regressions on different numbers of principal components are given in table 3 (the first column of each equation gives the unstandardized coefficients while the second column gives the standardized coefficients).

The table shows that the difference in results obtained by using different numbers of principal components are quite substantial. As was mentioned be-fore, the estimates in the last PCR equation (columns 17 and 18) involving all the nine possible principal components are the same as the OLS estimates, and as such, will not be considered. In other words, we need to choose one from among the other eight PCR equations. The criteria used here for choosing the best PCR equation are the stability of the coefficients, amount of information used, and percentage of variation explained. Let us consider equations (2.6) with $k = 7$ (columns 13 and 14), and $k = 8$ (columns 15 and 16). It is clear that the first seven principal components are associated with the combined effect of $X_1(URBAN)$, $X_5(FLITERACY)$, and $X_6(FPSCORE)$. These coefficients remained almost the same after adding the eighth principal component. The coefficients of other variables also remained almost the same.

The table shows that no other pair of equations reveals as much overall sta-bility as equations with $k = 7$ and $k = 8$

in (2.6). Each of these equations also explains 72 percent of the variation in the total fertility rate - almost the same amount as the OLS method explained. Thus, any of these two equations could be chosen. However, the equation with $k = 8$ is preferred since it uses eight principal components, and, therefore, uses almost all of the total amount of information contained in the data. Hence, the use of the equation with $k = 8$ is expected to reduce the amount of bias that will inevitably creep into the estimates. Thus, we

\Table 3: Principal component regression results for total fertility rate: Data for 43 developing countries.

Variable	First P.C. Equation (2.6) $k = 1$		First 2 P.C. Equation (2.6) $k = 2$		First 3 P.C. Equation (2.6) $k = 3$	
	(1)	(2)	(3)	(4)	(5)	(6)
URBAN	−.0081	−.0882	.0009	.0098	−.0073	−.0797
SWATER	−.0087	−.1268	−.0112	−.1623	−.0116	−.1687
DENSITY	.0001	.0194	−.0007	−.1856	−.0005	−.1209
CALORIE	−.0004	−.1125	−.0002	−.0541	−.0003	−.0688
FLITERACY	−.0070	−.1190	−.0082	−.1384	−.0120	−.2038
FPSCORE	−.0038	−.0637	−.0160	−.2670	−.0187	−.3127
IMR	.0052	.1276	.0077	.1890	.0101	.2446
ENERGY	−.0077	−.1135	−.0054	−.0791	.0038	.0555
GNP	−.0002	−.1248	−.0002	−.0888	.0000	.0244
CONSTANT	7.5873	0	7.1696	0	7.4354	0
$R^2 = 0.4301$			$R^2 = 0.5749$		$R^2 = 0.6341$	

Variable	First 4 P.C. Equation (2.6) $k = 4$		First 5 P.C. Equation (2.6) $k = 5$		First 6 P.C. Equation (2.6) $k = 6$	
	(7)	(8)	(9)	(10)	(11)	(12)
URBAN	−.0115	−.1246	−.0116	−.1254	−.0204	−.2211
SWATER	−.0114	−.1661	−.0094	−.1372	−.0156	−.2278
DENSITY	−.0006	−.1698	−.0006	−.1515	−.0004	−.1106
CALORIE	−.0003	−.0653	.0001	.0349	.0005	.1234
FLITERACY	−.0123	−.2078	−.0167	−.2828	−.0121	−.2043
FPSCORE	−.0170	−.2851	−.0165	−.2761	−.0216	−.3612
IMR	.0098	.2397	.0102	.2515	.0068	.1668
ENERGY	.0041	.0599	.0029	.0431	.0009	.0130
GNP	.0000	.0235	.0000	.0015	.0000	−.0028
CONSTANT	7.5450	0	6.7113	0	6.7779	0
	$R^2 = 0.6377$		$R^2 = 0.6477$		$R^2 = 0.6660$	

Variable	First 7 P.C. Equation (2.6) $k = 7$		First 8 P.C. Equation (2.6) $k = 8$		All 9 P.C's OLS eq. (2.1)	
	(13)	(14)	(15)	(16)	(17)	(18)
URBAN	−.0315	−.3421	−.0313	−.3400	−.0311	−.3378
SWATER	.0058	.0854	.0057	.0830	.0056	.0824
DENSITY	−.0003	−.0978	−.0003	−.0988	−.0003	−.0973
CALORIE	.0001	.0372	.0001	.0331	.0001	.0323
FLITERACY	−.0114	−.1933	−.0119	−.2024	−.0118	−.2008
FPSCORE	−.0328	−.5504	−.0329	−.5516	−.0332	−.5568
IMR	.0046	.1151	.0042	.1033	.0037	.0927
ENERGY	−.0043	−.0640	−.0043	−.0643	−.0008	−.0127
GNP	−.0001	−.0524	−.0001	−.0504	−.0001	−.1070
CONSTANT	7.6303	0	7.7414	0	7.8210	0
$R^2 = 0.7211$	$R^2 = 0.7212$		$R^2 = 0.7214$			

original variables, therefore,

Total Fertility Rate

$$= 7.7414 - 0.0314URBAN + 0.0057SWATER - 0.0004DENSITY + 0.0001CALORIE - 0.0120FLITERACY - 0.0330FPSCORE + 0.0042IMR - 0.0044ENERGY - 0.0001GNP.$$

The standardized coefficients are analyzed to assess the relative significance of the explanatory factors in affecting the overall fertility rate (table 3: column 16). According to the table, the family planning program effort has the greatest influence on reducing the overall fertility rate, as measured in standard deviation units. This is followed by the percentage of the population living in cities, the rate of female literacy, and the infant mortality rate. In fact, the effect of the family planning program effort is more than five times bigger than the infant mortality rate, more than 1.5 times greater than the percentage of urban population, and more than 2.5 times greater than the female literacy rate. According to the unstandardized coefficients, there are 0.033 fewer children per woman for every unit increase in the family planning program effort score, 0.031 fewer children per woman for every one percent increase in the urban population, 0.012 fewer children per woman for every one percent increase in the female literacy rate, and 0.004 more children per woman for every one per 1000 live births increase in infant mortality.

It should be noticed that the hypothesized directions of correlations with the overall fertility rate are present in six of the nine explanatory factors. The inverse correlations between the variables SWATER, CALORIE, and DENSITY are challenging to understand. It remains to be seen whether these linkages' unexpected tendencies will continue if more emerging nations are included in the investigation.

Summary and Conclusions

Fertility rates in developing nations have decreased over the last several decades, but they are still much higher than in wealthy nations. Given the plethora of issues brought on by the fast population expansion, it is critical to identify the relative weights of fertility drivers in emerging nations in order to determine priorities when designing population policy.

This study used national data for 43 countries to assess the cross-national variance in total fertility rate using principal component regression.

developing nations. Population density, per capita daily calories, female literacy rate, family planning program effort score, infant mortality rate, per capita energy use, and per capita gross national product are the explanatory variables that were employed.

According to the research, the family planning program effort has the greatest influence on the overall fertility rate, followed in order by the percentage of the population living in urban areas, the rate of female literacy, and the infant mortality rate. In fact, the impact of the family planning program effort is more than five times bigger than the infant mortality rate, more than 2.5 times greater than the female literacy rate, and more than 1.5 times greater than the percentage of the urban population.

There are many policy ramifications to this research. The most significant factor lowering the overall fertility rate is the family planning program. This supports the claim that the government's family planning initiatives have been the primary cause of the recent fertility reduction in emerging nations.

The proportion of the population living in cities is the second most significant factor; the larger this percentage, the lower the overall fertility rate. A greater proportion of people in emerging nations reside in rural regions. A significant portion of resources and social services are concentrated in urban regions, which are often the hubs of political and economic power. As a result, urban dwellers have comparatively greater access to contemporary options that support reduced family sizes.

The rate of female literacy is the third crucial factor. The overall fertility rate decreases as this literacy rate rises. Because they have greater access to life's prospects, women with higher levels of education see reduced fertility as more advantageous than higher fertility. Even a large difference in the number of children does not result in any discernible change in the standard of living for uneducated women; hence, decreased fertility does not seem to be a favorable condition in their lives. Therefore, civilizations with lower literacy rates are more likely to have higher fertility rates.

The newborn mortality rate is the last crucial factor; the greater the infant mortality rate, the higher the fertility rate. The favorable impact of newborn and

child mortality on fertility has been shown by several research (Adlakha, 1973; Taylor, Newman, and Kelly, 1976). The notion is theoretically connected to the premise of child survival. Married couples may have "extra" births to replace young children who have already passed away due to their experience with or dread of newborn and child mortality. Couples may also choose to adopt mod-

Use contraception only when they are certain that child mortality won't undermine their reproduction aim. Therefore, fertility tends to be greater in countries with higher infant mortality.

Therefore, even while family planning programs have been largely responsible for the recent decreases in fertility rates in developing nations, these drops shouldn't be attributed only to effective family planning programs. The analysis's findings suggest that increasing female literacy, lowering infant mortality, and distributing the advantages of socioeconomic development equally between rural and urban areas could be key tactics for lowering fertility rates in developing nations.

The online version of JDS provides the data utilized in the study.

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