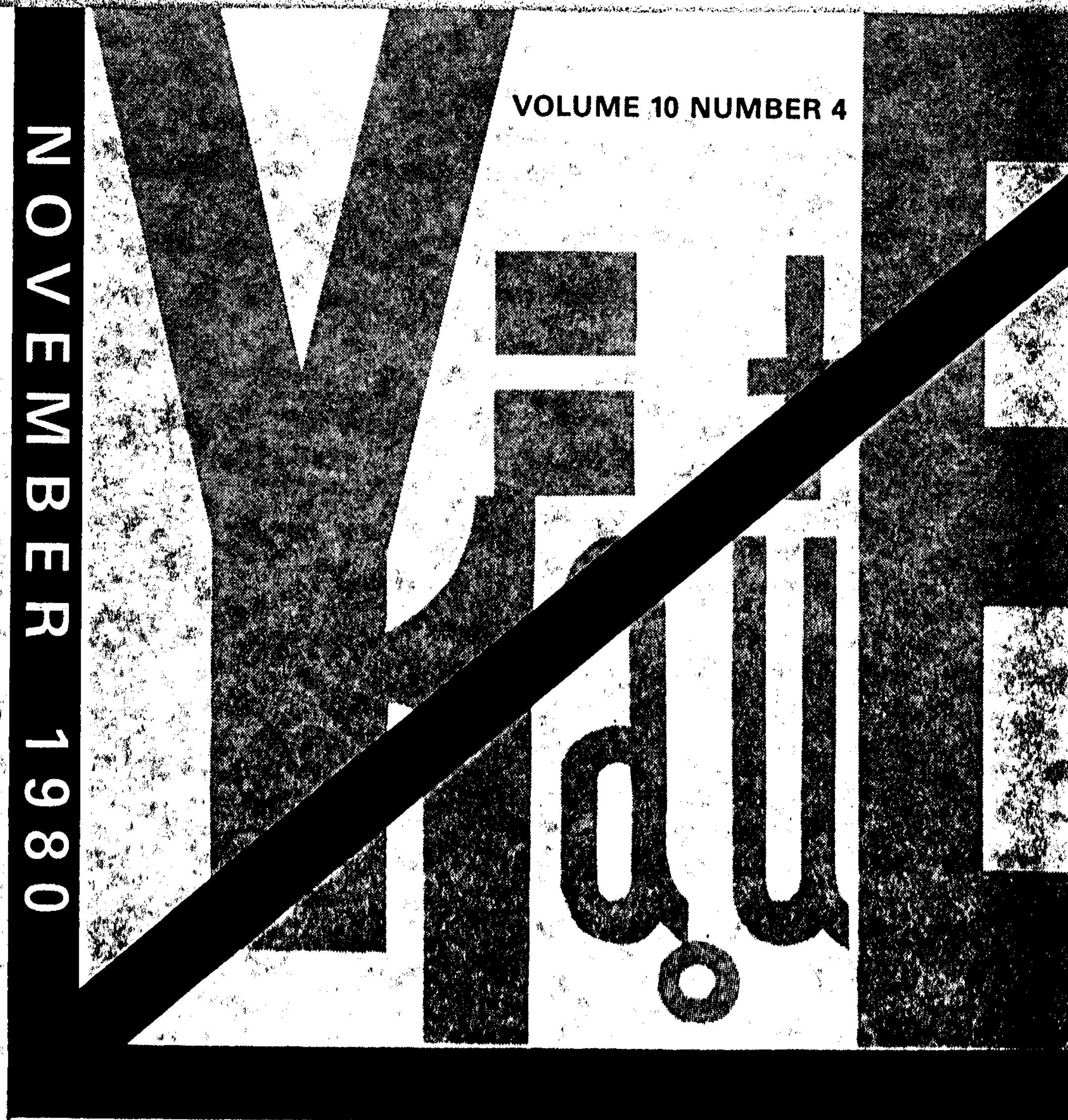
VOLUME 10 NUMBER 4




# MULTIPLE LINEAR REGRESSION VIEWPOINTS

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## MULTIPLE LINEAR REGRESSION VIEWPOINTS

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November 1980, Volume 10, Number 4

# MULTIPLE LINEAR REGRESSION AND LARGE SCALE INTEGRATION TECHNOLOGY APPLICATION TO THE TEXAS INSTRUMENT TI-59

William C. Croom
The University of Akron

The use of MLR as a general model-testing system has, over the last few years, provided the user with a powerful, flexible research tool (Newman, 1976' McNeil, K.; Kelly, F.; McNeil, J 1975). Except for the most simple cases (e.g. two or three variables), MLR has, unfortunately, been limited in application to those who have easy access to a large computer, or at least to those who are in contact with individuals who have such access. Thus, the smaller agencies, private practitioners, consultants, schools and the like may well have information which could be evaluated by MLR but is evaluated (if at all) by more traditional statistical procedures which may be inappropriate for the research question being asked, or suffer from insufficient power to discriminate real differences (Roll, S.; Hoedt, K.; Newman, I. 1979).

The program below was written to allow the occasional user of MLR to take advantage of the features of the Texas Instrument TI-59 hand-held programmable calculator. The program may be recorded on magnetic cards which are supplied with the calculator; at the time of this writing, the instrument sells for approximately $225.00.

Once so equipped, the user may then perform up to seven-variable regression routines with unlimited replications - since all other regression routines for hand-held calculators manipulate at most two independent variables the gain may well be worth the cost.

Definitions: string - one ordered series of data ($X_1$, $X_2$. . .Y)

set - K strings, where K = number of replications or subjects

vector - K replications of each variable; e.g., all $X_1$ scores

## Description of Program

This program takes ordered strings of data and 1) creates a raw-score sum-of-squares-and-cross-products matrix (SSCP), 2) provides a fast, efficient method of constructing a correlation matrix from the SSCP matrix, 3) computes means and standard deviations for all variables,

4) calculates slopes and intercepts for any combination of two vectors taken as a X-Y pair, 5) provides a least-squares solution for a multiple regression analysis, where predictor variables (N = 1-6) are regressed on one criterion, then computes regression coefficients (raw-score) for these predictors, and 6) computes $R^2$, the variance in the criterion accounted for by the linear combination of predictors. Input data may be any combination of discrete or continuous variables.

Limitation, Error Recovery, Notes

1. This program uses the matrix-inversion method of calculating the regression coefficients. If a singularity (determinant = 0) exists in the data, computation of the coefficients and $R^2$ will result in serious errors. Means, standard deviations, slopes, intercepts and individual correlations, among score vectors may be calculated without error. However, the user is encouraged to examine the data for "logical" perfect correlations (e.g. 1 if male, 0 otherwise, etc.). If the optional TI print cradle is used with this program, the determinant of the SSCP matrix will be printed and may then be easily examined.

2. Program execution of each string ($X_1$, $X_2$...Y) of raw data requires approximately 10 seconds per variable.

3. Error recovery before the final variable of a string is entered with the R/S Key merely involves pressing SBR $Y^x$

and re-entering the string beginning with the first variable. If an error is discovered after value Y is entered in the calculator with the R/S Key, the matter is considerably more complicated. Recovery now involves expanding that particular data string into its own SSCP matrix and subtracting each value from the corresponding memory location in the calculator. This process is so lengthy and error-prone, it is recommended that the user press E and start over. Note that the use of the optional printer greatly reduces the chanoe of key punch error.

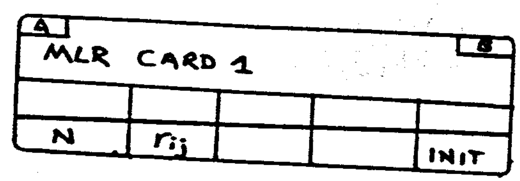
4. Note that it is not necessary to perform all steps if only regression coefficients are required - the user may jump directly from step 7 to step 19.

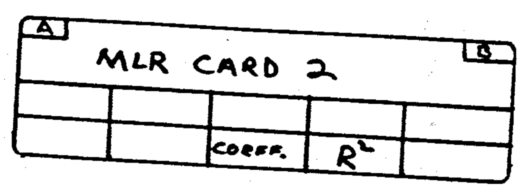
On the following pages appears the program. *TI-59 is a registered trademark of Texas Instruments, Inc.

| STEP | ENTER | PRESS | DISPLAY | COMMENTS |
|---|---|---|---|---|
| STARTUP<br>1. Repartition calculator | 8 | (2nd) OP 17 | 319.79 | 320 pgm steps/80 memories |
| 2. Load side A/card 1 into Bank 1 | 1 | RST | 1 | Bank 1 read from side A of card 1 |
| 3. Load side B/card 1 into Bank 2 | 2 | — | 2 | Bank 2 read from side B of card 1 |
| DATA LOAD<br>4. initialize | — | E | (current) | clears memories and T-register, resets SBR counter |
| 5. Enter # of predictors | N | A | 0 | $N \leq 6$ |
| 6. Enter predictor raw scores in order; e.g., $X_1$, $X_2$, $X_3 \ldots X_n$, then criterion score (Y) which is defined as $X_{n+1}$ | $X_1$<br>$X_2$<br>⋮<br>$X_{n+1}$ | R/S<br>R/S<br>⋮<br>R/S | —<br>—<br>—<br>—<br>K | at $X_{n+1}$, calculator will process the set of scores. display will blank, then display K, the number of that data set (where K = 1, 2, 3,... K = number of sets of scores) |
| 7. Repeat (6) until all replications are entered | | | | |
| TO COMPUTE CORRELATIONS<br>Perform steps 1-7 first.<br>8. initialize correlation sub-routine | — | B | 0 | $r_{ij}$ = correlation between variable i and j |
| 9. compute $r_{ij}$ | i<br>j | R/S<br>R/S | i<br>$r_{ij}$ | enter data so $i < j$; e.g. (1, 2) not (2, 1). note: $j \leq n+1$ where variable $n+1 = y$, the criterion variable, thus, with 2 predictors, 1,3 would calculate correlation between $X_1$ and Y |
| 10. To compute additional correlations, repeat 8-9. | | | | |

| STEP | ENTER | PRESS | DISPLAY | COMMENTS |
| --- | --- | --- | --- | --- |
| MEANS, STD. DEVS., SLOPES, INTERCEPTS, $\hat{X}$, $\hat{Y}$ | | | | |
| 11. Perform steps 8-9 first. | | | | |
| 12. Compute $\overline{X}_j$ | — | R/S | $\overline{X}_j$ | mean of 2nd variable entered |
| 13. Compute $\overline{X}_i$ | — | R/S | $\overline{X}_i$ | mean of 1st variable entered |
| 14. Compute $SD_j$ | — | R/S | $SD_j$ | standard deviation of 2nd variable entered |
| 15. Compute $SD_i$ | — | R/S | $SD_i$ | standard deviation of 1st variable entered |
| 16. To compute slope and intercept of ij pair - perform steps 8-9 first, then: | —<br>— | (2nd) OP 12<br>$X \rightleftarrows t$ | a<br>b | intercept, a<br>slope, b |
| 17. Compute $\hat{Y}$ from X | X | (2nd) OP 14 | $\hat{Y}$ | estimate of Y computed from X |
| 18. Compute $\hat{X}$ from Y | Y | (2nd) OP 15 | $\hat{X}$ | estimate of X computed from Y |
| CALCULATE REGRESSION COEFFICIENTS | | | | |
| 19. Perform steps 1-7 first | | | | |
| 20. Save raw-data matrix on magnetic card 3 - insert side A | 3 | (2nd) write | 3 | Bank 3 written on side A of card 3 |
| 21. Insert Side B | 4 | (2nd) write | 4 | Bank 4 written on side B of card 3 |
| 22. Read side A of card 2 into Bank 1 | 1 | RST | 1 | Bank 1 read from side A of card 2 |
| 23. Calculate regression coefficients: | — | C<br>R/S<br>⋮<br>R/S | $a_o$<br>$a_1$<br>⋮<br>$a_i$ | constant ($a_o u$)<br>regression coefficients for $X_1$<br>⋮<br>regression coefficient for $X_n$<br>Note: press R/S until a "0" appears in the display—this insures all coefficients are calculated and stored in the calculator memory |
| CALCULATE $R^2$ | | | | |
| 24. Calculate regression coefficients first | | | | |

| STEP | ENTER | PRESS | DISPLAY | COMMENTS |
|---|---|---|---|---|
| 25. Read side A of data card 3 into Bank 3 | 3 | — | 3 | Bank 3 read from side A of card 3 |
| 26. Read side B of data card 3 into Bank 4 | 4 | — | 4 | Bank 4 read from side B of card 3 |
| 27. Read side B of card 2 into Bank 1 | 1 | — | 1 | Bank 1 read from side B of card 2 |
| 28. Calculate $R^2$ | — | D | $R^2$ | proportion of variance in Y accounted for by the linear combination of predictors |



| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 00 | 76 | LBL | |
| | 11 | A | |
| | 42 | STO | |
| | 59 | 59 | |
| | 32 | X⇄t | |
| | 76 | LBL | |
| | 45 | $Y^x$ | |
| | 00 | 0 | |
| | 42 | STO | |
| | 00 | 00 | |
| 10 | 06 | 6 | |
| | 00 | 0 | |
| | 42 | STO | |
| | 01 | 01 | |
| | 01 | 1 | |
| | 72 | ST* | |
| | 01 | 01 | |
| | 69 | OP | |
| | 21 | 21 | |
| | 43 | RCL | |
| 20 | 08 | 08 | |
| | 91 | R/S | |
| | 99 | PRT | |
| | 72 | ST* | |
| | 01 | 01 | |
| | 69 | OP | |
| | 20 | 20 | |
| | 69 | OP | |
| | 21 | 21 | |
| | 43 | RCL | |
| 30 | 00 | 00 | |
| | 67 | EQ | |
| | 22 | INV | |
| | 61 | GTO | |
| | 00 | 00 | |
| | 19 | 19 | |
| | 76 | LBL | |
| | 22 | INV | |
| | 91 | R/S | |
| | 99 | PRT | |
| 40 | 42 | STO | |
| | 70 | 70 | |
| | 06 | 6 | |
| | 00 | 0 | |
| | 42 | STO | |
| | 00 | 00 | |
| | 42 | STO | |
| | 01 | 01 | |
| | 00 | 0 | |
| | 42 | STO | |
| 50 | 02 | 02 | |
| | 42 | STO | |
| | 03 | 03 | |
| | 08 | 8 | |
| | 42 | STO | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| | 04 | 04 | |
| | 07 | 7 | |
| | 01 | 1 | |
| | 42 | STO | |
| | 05 | 05 | |
| 60 | 76 | LBL | |
| | 23 | LNX | |
| | 53 | ( | |
| | 73 | RC* | |
| | 00 | 00 | |
| | 65 | × | |
| | 73 | RC* | |
| | 01 | 01 | |
| | 54 | ) | |
| | 74 | SM* | |
| 70 | 04 | 04 | |
| | 43 | RCL | |
| | 02 | 02 | |
| | 67 | EQ | |
| | 24 | CE | |
| | 69 | OP | |
| | 20 | 20 | |
| | 69 | OP | |
| | 22 | 22 | |
| | 69 | OP | |
| 80 | 24 | 24 | |
| | 61 | GTO | |
| | 23 | LNX | |
| | 76 | LBL | |
| | 24 | CE | |
| | 69 | OP | |
| | 24 | 24 | |
| | 69 | OP | |
| | 20 | 20 | |
| | 53 | ( | |
| 90 | 73 | RC* | |
| | 00 | 00 | |
| | 65 | × | |
| | 73 | RC* | |
| | 01 | 01 | |
| | 54 | ) | |
| | 74 | SM* | |
| | 04 | 04 | |
| | 53 | ( | |
| | 73 | RC* | |
| 100 | 01 | 01 | |
| | 65 | × | |
| | 43 | RCL | |
| | 70 | 70 | |
| | 54 | ) | |
| | 74 | SM* | |
| | 05 | 05 | |
| | 43 | RCL | |
| | 03 | 03 | |
| | 67 | EQ | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 110 | 34 | $\sqrt{x}$ | |
| | 06 | 6 | |
| | 00 | 0 | |
| | 42 | STO | |
| | 00 | 00 | |
| | 69 | OP | |
| | 21 | 21 | |
| | 69 | OP | |
| | 23 | 23 | |
| | 69 | OP | |
| 120 | 25 | 25 | |
| | 00 | 0 | |
| | 42 | STO | |
| | 02 | 02 | |
| | 61 | GTO | |
| | 23 | LNX | |
| | 76 | LBL | |
| | 34 | $\sqrt{x}$ | |
| | 69 | OP | |
| | 25 | 25 | |
| 130 | 43 | RCL | |
| | 70 | 70 | |
| | 33 | $x^2$ | |
| | 74 | SM* | |
| | 05 | 05 | |
| | 98 | ADV | |
| | 61 | GTO | |
| | 45 | $Y^x$ | |
| | 76 | LBL | |
| | 15 | E | |
| 140 | 47 | CMS | |
| | 29 | CP | |
| | 92 | RTN | |
| | 76 | LBL | |
| | 12 | B | |
| | 98 | ADV | |
| | 98 | ADV | |
| | 00 | 0 | |
| | 42 | STO | |
| | 07 | 07 | |
| 150 | 42 | STO | |
| | 00 | 00 | |
| | 29 | CP | |
| | 91 | R/S | |
| | 99 | PRT | |
| | 42 | STO | |
| | 68 | 68 | |
| | 91 | R/S | |
| | 99 | PRT | |
| | 42 | STO | |

SIDES A & B, CARD 1 (cont.)

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 160 | 69 | 69 | |
| | 43 | RCL | |
| | 68 | 68 | |
| | 42 | STO | |
| | 07 | 07 | |
| | 71 | SBR | |
| | 35 | 1/x | |
| | 42 | STO | |
| | 04 | 04 | |
| | 43 | RCL | |
| 170 | 68 | 68 | |
| | 42 | STO | |
| | 00 | 00 | |
| | 71 | SBR | |
| | 35 | 1/x | |
| | 42 | STO | |
| | 06 | 06 | |
| | 43 | RCL | |
| | 59 | 59 | |
| | 85 | + | |
| 180 | 01 | 1 | |
| | 54 | ) | |
| | 32 | x≷t | |
| | 43 | RCL | |
| | 69 | 69 | |
| | 67 | EQ | |
| | 96 | WRT | |
| | 29 | CP | |
| | 00 | 0 | |
| | 42 | STO | |
| 190 | 07 | 07 | |
| | 43 | RCL | |
| | 69 | 69 | |
| | 42 | STO | |
| | 00 | 00 | |
| | 71 | SBR | |
| | 35 | 1/x | |
| | 42 | STO | |
| | 01 | 01 | |
| | 43 | RCL | |
| 200 | 69 | 69 | |
| | 42 | STO | |
| | 07 | 07 | |
| | 71 | SBR | |
| | 36 | 1/x | |
| | 42 | STO | |
| | 02 | 02 | |
| | 43 | RCL | |
| | 68 | 68 | |
| | 42 | STO | |
| 210 | 07 | 07 | |
| | 43 | RCL | |
| | 69 | 69 | |
| | 42 | STO | |
| | 00 | 00 | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| | 71 | SBR | |
| | 35 | 1/x | |
| | 42 | STO | |
| | 06 | 06 | |
| | 43 | RCL | |
| 220 | 08 | 08 | |
| | 42 | STO | |
| | 03 | 03 | |
| | 61 | GTO | |
| | 78 | Σ+ | |
| | 76 | LBL | |
| | 96 | WRT | |
| | 43 | RCL | |
| | 71 | 71 | |
| | 42 | STO | |
| 230 | 01 | 01 | |
| | 07 | 7 | |
| | 02 | 2 | |
| | 85 | + | |
| | 43 | RCL | |
| | 59 | 69 | |
| | 54 | ) | |
| | 42 | STO | |
| | 00 | 00 | |
| | 73 | RC* | |
| 240 | 00 | 00 | |
| | 42 | STO | |
| | 02 | 02 | |
| | 07 | 7 | |
| | 01 | 1 | |
| | 85 | + | |
| | 43 | RCL | |
| | 68 | 68 | |
| | 54 | ) | |
| | 42 | STO | |
| 260 | 00 | 00 | |
| | 73 | RC* | |
| | 00 | 00 | |
| | 42 | STO | |
| | 06 | 06 | |
| | 43 | RCL | |
| | 08 | 08 | |
| | 42 | STO | |
| | 03 | 03 | |
| | 61 | GTO | |
| 260 | 78 | Σ+ | |
| | 76 | LBL | |
| | 78 | Σ+ | |
| | 69 | OP | |
| | 13 | 13 | |
| | 99 | PRT | |
| | 91 | R/S | |
| | 79 | x̄ | |
| | 99 | PRT | |
| | 91 | R/S | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 270 | 32 | x≷t | |
| | 99 | PRT | |
| | 91 | R/S | |
| | 22 | INV | |
| | 79 | x̄ | |
| | 99 | PRT | |
| | 91 | R/S | |
| | 32 | x≷t | |
| | 99 | PRT | |
| | 92 | RTN | |
| 280 | 76 | LBL | |
| | 35 | 1/x | |
| | 43 | RCL | |
| | 07 | 07 | |
| | 65 | × | |
| | 53 | ( | |
| | 43 | RCL | |
| | 59 | 59 | |
| | 85 | + | |
| | 01 | 1 | |
| 290 | 54 | ) | |
| | 85 | + | |
| | 43 | RCL | |
| | 00 | 00 | |
| | 85 | + | |
| | 08 | 8 | |
| | 54 | ) | |
| | 42 | STO | |
| | 67 | 67 | |
| | 73 | RC* | |
| 300 | 67 | 67 | |
| | 92 | RTN | |

END OF CARD 1
Sides A and B

SIDE A, CARD 2

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 000 | 76 | LBL | |
| | 13 | C | |
| | 25 | CLR | |
| | 48 | EXC | |
| | 59 | 59 | |
| | 32 | X≷t | |
| | 25 | CLR | |
| | 06 | 6 | |
| | 02 | 2 | |
| | 42 | STO | |
| 010 | 61 | 61 | |
| | 32 | X≷t | |
| | 85 | + | |
| | 01 | 1 | |
| | 54 | ) | |
| | 42 | STO | |
| | 79 | 79 | |
| | 36 | PGM | |
| | 01 | 01 | |
| | 71 | SBR | |
| 020 | 25 | CLR | |
| | 01 | 1 | |
| | 32 | X≷t | |
| | 43 | RCL | |
| | 79 | 79 | |
| | 42 | STO | |
| | 07 | 07 | |
| | 36 | PGM | |
| | 02 | 02 | |
| | 13 | C | |
| 030 | 01 | 1 | |
| | 94 | +/- | |
| | 42 | STO | |
| | 79 | 79 | |
| | 07 | 7 | |
| | 01 | 1 | |
| | 42 | STO | |
| | 00 | 00 | |
| | 01 | 1 | |
| | 36 | PGM | |
| 040 | 02 | 02 | |
| | 14 | D | |
| | 76 | LBL | |
| | 52 | EE | |
| | 73 | RC* | |
| | 00 | 00 | |
| | 36 | PGM | |
| | 02 | 02 | |
| | 91 | R/S | |
| | 43 | RCL | |
| 050 | 07 | 07 | |
| | 75 | − | |
| | 01 | 1 | |
| | 54 | ) | |
| | 32 | X≷t | |
| | 01 | 1 | |
| | 44 | SUM | |
| | 79 | 79 | |
| | 69 | OP | |
| | 20 | 20 | |
| 060 | 43 | RCL | |
| | 79 | 79 | |
| | 67 | EQ | |
| | 44 | SUM | |
| | 61 | GTO | |
| | 52 | EE | |
| | 76 | LBL | |
| | 44 | SUM | |
| | 25 | CLR | |
| | 36 | PGM | |
| 070 | 02 | 02 | |
| | 15 | E | |
| | 01 | 1 | |
| | 36 | PGM | |
| | 02 | 02 | |
| | 16 | A' | |
| | 76 | LBL | |
| | 65 | × | |
| | 36 | PGM | |
| | 02 | 02 | |
| 080 | 91 | R/S | |
| | 91 | R/S | |
| | 72 | ST* | |
| | 61 | 61 | |
| | 01 | 1 | |
| | 44 | SUM | |
| | 61 | 61 | |
| | 61 | GTO | |
| | 65 | × | |
| | 92 | RTN | |
| 090 | | | |

END OF SIDE A CARD 2

SIDE B, CARD 2

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 00 | 76 | LBL | |
| | 14 | D | |
| | 36 | PGM | |
| | 01 | 01 | |
| | 71 | SBR | |
| | 25 | CLR | |
| | 43 | RCL | |
| | 71 | 71 | |
| | 55 | ÷ | |
| | 43 | RCL | |
| 10 | 08 | 08 | |
| | 54 | ) | |
| | 42 | STO | |
| | 01 | 01 | |
| | 07 | 7 | |
| | 02 | 2 | |
| | 42 | STO | |
| | 02 | 02 | |
| | 43 | RCL | |
| | 79 | 79 | |
| 20 | 42 | STO | |
| | 04 | 04 | |
| | 43 | RCL | |
| | 79 | 79 | |
| | 85 | + | |
| | 09 | 9 | |
| | 54 | ) | |
| | 42 | STO | |
| | 03 | 03 | |
| | 76 | LBL | |
| 30 | 37 | P/R | |
| | 73 | RC* | |
| | 03 | 03 | |
| | 65 | × | |
| | 43 | RCL | |
| | 01 | 01 | |
| | 54 | ) | |
| | 94 | +/- | |
| | 74 | SM* | |
| | 02 | 02 | |
| 40 | 69 | OP | |
| | 34 | 34 | |
| | 43 | RCL | |
| | 04 | 04 | |
| | 67 | EQ | |
| | 49 | PRD | |
| | 69 | OP | |
| | 22 | 22 | |
| | 43 | RCL | |
| | 79 | 79 | |
| 50 | 85 | + | |
| | 01 | 1 | |
| | 54 | ) | |
| | 44 | SUM | |
| | 03 | 03 | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| | 61 | GTO | |
| | 37 | P/R | |
| | 76 | LBL | |
| | 49 | PRD | |
| | 43 | RCL | |
| 60 | 79 | 79 | |
| | 85 | + | |
| | 07 | 7 | |
| | 02 | 2 | |
| | 54 | ) | |
| | 42 | STO | |
| | 00 | 00 | |
| | 43 | RCL | |
| | 71 | 71 | |
| | 33 | $X^2$ | |
| 70 | 55 | ÷ | |
| | 43 | RCL | |
| | 08 | 08 | |
| | 54 | ) | |
| | 94 | +/- | |
| | 85 | + | |
| | 73 | RC* | |
| | 00 | 00 | |
| | 54 | ) | |
| | 42 | STO | |
| 80 | 00 | 00 | |
| | 36 | PGM | |
| | 01 | 01 | |
| | 71 | SBR | |
| | 25 | CLR | |
| | 43 | RCL | |
| | 79 | 79 | |
| | 42 | STO | |
| | 30 | 30 | |
| | 43 | RCL | |
| 90 | 00 | 00 | |
| | 35 | 1/X | |
| | 42 | STO | |
| | 00 | 00 | |
| | 06 | 6 | |
| | 03 | 3 | |
| | 42 | STO | |
| | 61 | 61 | |
| | 07 | 7 | |
| | 02 | 2 | |
| 100 | 42 | STO | |
| | 71 | 71 | |
| | 01 | 1 | |
| | 36 | PGM | |
| | 03 | 03 | |
| | 11 | A | |
| | 43 | RCL | |
| | 79 | 79 | |
| | 36 | PGM | |
| | 03 | 03 | |

| LOC | CODE | KEY | COMMENTS |
|---|---|---|---|
| 110 | 11 | A | |
| | 01 | 1 | |
| | 36 | PGM | |
| | 03 | 03 | |
| | 12 | B | |
| | 76 | LBL | |
| | 38 | SIN | |
| | 73 | RC* | |
| | 61 | 61 | |
| | 36 | PGM | |
| 120 | 03 | 03 | |
| | 91 | R/S | |
| | 01 | 1 | |
| | 22 | INV | |
| | 44 | SUM | |
| | 30 | 30 | |
| | 25 | CLR | |
| | 32 | X⇄t | |
| | 48 | EXC | |
| | 30 | 30 | |
| 130 | 67 | EQ | |
| | 50 | \|x\| | |
| | 48 | EXC | |
| | 30 | 30 | |
| | 32 | X⇄t | |
| | 01 | 1 | |
| | 44 | SUM | |
| | 61 | 61 | |
| | 61 | GTO | |
| | 38 | SIN | |
| 140 | 76 | LBL | |
| | 50 | \|x\| | |
| | 43 | RCL | |
| | 79 | 79 | |
| | 42 | STO | |
| | 30 | 30 | |
| | 01 | 1 | |
| | 36 | PGM | |
| | 03 | 03 | |
| | 17 | B' | |
| 150 | 76 | LBL | |
| | 60 | DEG | |
| | 73 | RC* | |
| | 71 | 71 | |
| | 36 | PGM | |
| | 03 | 03 | |
| | 91 | R/S | |
| | 01 | 1 | |
| | 22 | INV | |
| | 44 | SUM | |

SIDE B, CARD 2 (cont.)

| LOC | CODE | KEY | COMMENTS | LOC | CODE | KEY | COMMENTS | LOC | CODE | KEY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 | 30 | 30 | | | | | | | | | |
| | 25 | CLR | | | | | | | | | |
| | 32 | X≷t | | | | | | | | | |
| | 48 | EXC | | | | | | | | | |
| | 30 | 30 | | | | | | | | | |
| | 67 | EQ | | 220 | | | | | | | |
| | 80 | GRD | | | | | | | | | |
| | 48 | EXC | | | | | | | | | |
| | 30 | 30 | | | | | | | | | |
| | 32 | X≷t | | | | | | | | | |
| 170 | 01 | 1 | | | | | | | | | |
| | 44 | SUM | | | | | | | | | |
| | 71 | 71 | | | | | | | | | |
| | 61 | GTO | | | | | | | | | |
| | 60 | DEG | | | | | | | | | |
| | 76 | LBL | | | | | | | | | |
| | 80 | GRD | | | | | | | | | |
| | 36 | PGM | | | | | | | | | |
| | 03 | 03 | | | | | | | | | |
| | 18 | C' | | | | | | | | | |
| 180 | 01 | 1 | | | | | | | | | |
| | 36 | PGM | | | | | | | | | |
| | 03 | 03 | | | | | | | | | |
| | 19 | D' | | | | | | | | | |
| | 36 | PGM | | | | | | | | | |
| | 03 | 03 | | | | | | | | | |
| | 91 | R/S | | | | | | | | | |
| | 65 | x | | | | | | | | | |
| | 43 | RCL | | | | | | | | | |
| | 00 | 00 | | | | | | | | | |
| 190 | 95 | = | | | | | | | | | |
| | 42 | STO | | | | | | | | | |
| | 00 | 00 | | | | | | | | | |
| | 00 | 0 | | | | | | | | | |
| | 00 | 0 | | | | | | | | | |
| | 03 | 3 | | | | | | | | | |
| | 05 | 5 | | | | | | | | | |
| | 07 | 7 | | | | | | | | | |
| | 00 | 0 | | | | | | | | | |
| | 00 | 0 | | | | | | | | | |
| 200 | 00 | 0 | | | | | | | | | |
| | 00 | 0 | | | | | | | | | |
| | 00 | 0 | | | | | | | | | |
| | 69 | OP | | | | | | | | | |
| | 04 | 04 | | | | | | | | | |
| | 43 | RCL | | | | | | | | | |
| | 00 | 00 | | | | | | | | | |
| | 69 | OP | | | | | | | | | |
| | 06 | 06 | | | | | | | | | |
| | 92 | RTN | | | | | | | | | |
| 210 | | | | | | | | | | | |

END OF Side B CARD 2

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MULTIPLE LINEAR REGRESSION VIEWPOINTS
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# RELATIONSHIPS AMONG PREDICTORS IN LONGITUDINAL DATA: TEMPORAL-SEQUENTIAL ANALYSIS BY REGRESSION - TSAR

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In analyses of longitudinal data attention is appropriately drawn to criterion measures of growth. However, it seems appropriate to consider predictor variables, and to do so in a fashion which helps understand their interrelationships. A method of arranging predictors is described which draws on regression analysis, and so uses powerful inferential tests of statistical significance. Examples are given of patterns of predictors educed by representative analyses. Data are drawn from two data sets with attention to several measures in the first 5-6 years of life of a particular cohort, and to demographic data on childhood from several countries of the world, in the second instance.

## INTRODUCTION

In analyses employing data across a span of interest in the cycle of development there is a not unreasonable concentration on the criterion measure. This is because study of the criterion is the step which leads to assessment of a hypothesis about a stage of growth. To a lesser extent we concentrate on the factors which explain the criterion data, with a view to understanding the quantitative influences on a particular level of attainment.

Study of predictor variables tends to focus on them as sources of variance, and combines them in the form of statistical interactions as a particular mode of analysis will permit, and as reasoning can subsequently decipher into non-mathematical, operational propositions. We tend to neglect the total array of predictor variables in a set, except as we engage in path analyses. In such studies the goal, however, tends to be pursuit of the criterion and the linkage via regression weights to the dependent measure. In addition, use of path analysis presumes stability of regression weights; also, it has tended to slight inferential tests of significance and ignores statistical interactions.

It is interesting to consider how predictors in longitudinal data sets may relate to each other. We can give each the status of a criterion whose variance may be understood in the constellation of all predictors, with inferential tests of statistical significance. To this end it is helpful to draw on regression analysis, and on multiple linear regression (Bottenberg and Ward, 1963; McNeil, Kelley, and McNeil, 1975) in particular. The latter technique has been particularly useful in analyses of longitudinal data (Jordan, 1980). The origin of this interest emerges from analyzing the data set of the St. Louis Baby Study (Jordan, 1981a), an inquiry into the developmental span beginning at birth and continuing into adolescence. In these analyses predictor variables are typically arrayed from a variety of domains in order to test hypotheses of relative influence on a developmental criterion (Jordan, 1978). Theoretically, predictors are independent of each other, but there may be dependencies due to the conceptual or practical relevance of a given predictor in the presence of another variable for which the case is equally strong (e.g. from another theoretical domain of influences). This equivalence of a claim to significance may be due to the nature of the model we are examining, despite the statistical shortcomings that situation may precipitate. However, we mention that in passing; the greater point is that predictors as a data set may need as much attention as the larger aggregate which includes the criterion.

## PROBLEM

The particular topic we address here is the matter of an empirical structure of relationships among predictors based on inferential statistical significance (F-tests) and employing regression analysis because of its utility for longitudinal data. We start by noting that measures gathered by prospective case studies are time specific, and occur in a sequence as a consequence. Our problem is the search for an empirically derived schema which reflects the sequence of predictor variables in their temporal order. We do so without prior commitment to structures which will stress the dependent variable, as in path analysis to which our approach has a superficial similarity in use of diagrams with arrows.

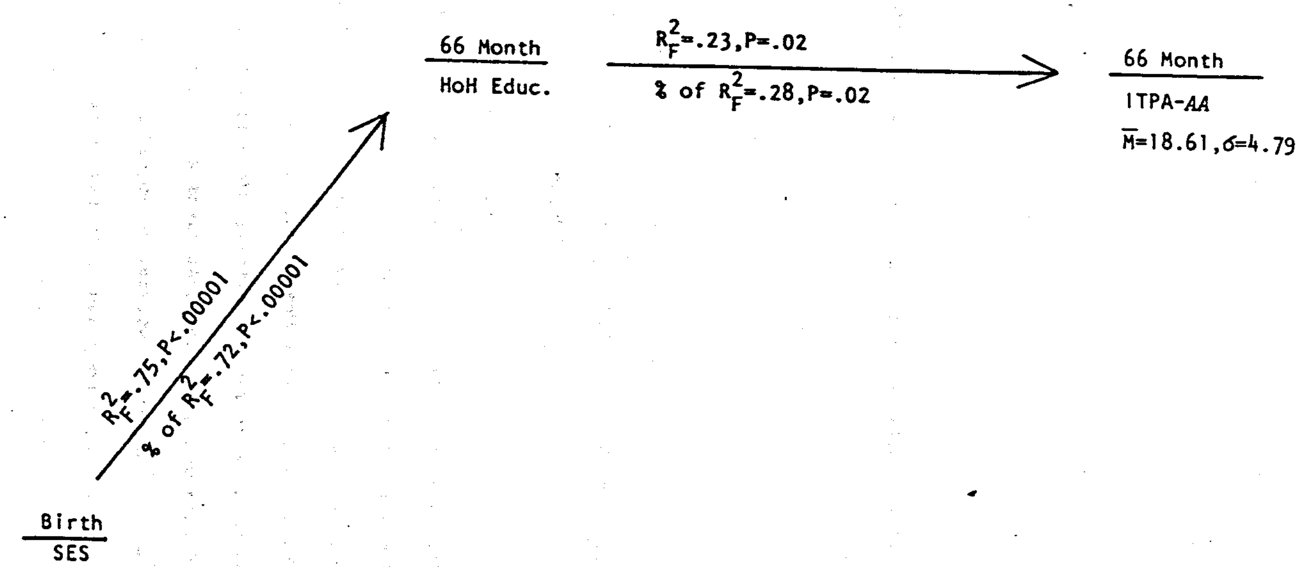
## METHOD

In multiple linear regression (McNeil, Kelley, and McNeil, 1975), a regression equation is developed in order to predict a criterion. A critical element is deleted or collapsed, the resulting equation is designated as an alternate mode, and an $F$ value is computed for the loss of predictive efficiency traceable to the altered vector. The basic model may be illustrated as $Y = a_0u + a_1x_1 + a_2x_2 \ldots a_nx_n + e$, where $Y$ = a criterion of continuous or discrete data, $u$ = a unit vector which when multiplied by the weight $a_0$ yields the regression constant, $a_1a_2 \ldots a_n$ = partial regression weights arrived at by multuple linear regression techniques and calculated to minimize the error sums of squares of prediction $(\Sigma e^2)$, $x_1x_2 \ldots x_n$ = variables in continuous or discrete form, and $e$ = error in predicting a criterion.

When applied to a temporal-sequential data set $Y$ becomes each variable linked to its temporal antecedents and successors, in a regression model which, ideally, incorporates all relevant predictors. Our goal, however, is not to report all significant outcomes, but to schematize those relationships which

FIGURE 1

TSAR ANALYSIS OF PREDICTORS AT BIRTH, 42, 54, AND 66 MONTHS, AND 66 MONTH ITPA *Auditory Association* SCORES-HIGH GROUP (N=54)



are statistically significant in the temporal sequence. By this we mean that (e.g.) SES level at conception and perinatal complications may well be statistically significant as predictors when the other is a criterion. However, the logic of examining perinatal complications as a statistically significant source of SES variance nine months before makes no sense when compared with the opposite proposition. The putative contribution of SES to variance associated with complications at birth nine months after conception would be a rational statement of hypothetical influence and its temporal direction.

## FINDINGS

We wish to illustrate some insights gained by using multiple linear regression to derive a temporal-sequential analysis by regression (*TSAR*) with data from the St. Louis Baby Study. We begin by reporting an analysis of data at birth, 42, 54, and 66 months employing some predictors (a TSAR schema) of mental test performance. The predictors shown in Figure I were derived from previous research into salient influences in several independent domains on cognitive attainment.

In Figure I we see data from the developmental histories of 54 bright children. This TSAR schema was derived from a set of five predictors and shows the simplest of all linkages, one in which a predictor in a temporal sequence, perinatal SES (McGuire and White, 1955), is linked statistically to another predictor, the level of education of the head of the household at age 66 months, and then to the criterion. In this analysis three predictors in the full set did not play a statistically significant role, and are not evident in the schema.

In Figure 2 is a schema of four predictors, none of which is the statistically insignificant Apgar score (Apgar and James, 1962) at birth, and a criterion score at child age sixty six months. In this TSAR schema we see

TSAR SCHEMA OF PREDICTORS AT BIRTH, 54 AND 66 MONTHS AND

66 MONTH WPPSI *Vocabulary* CRITERION SCORES (N=348)

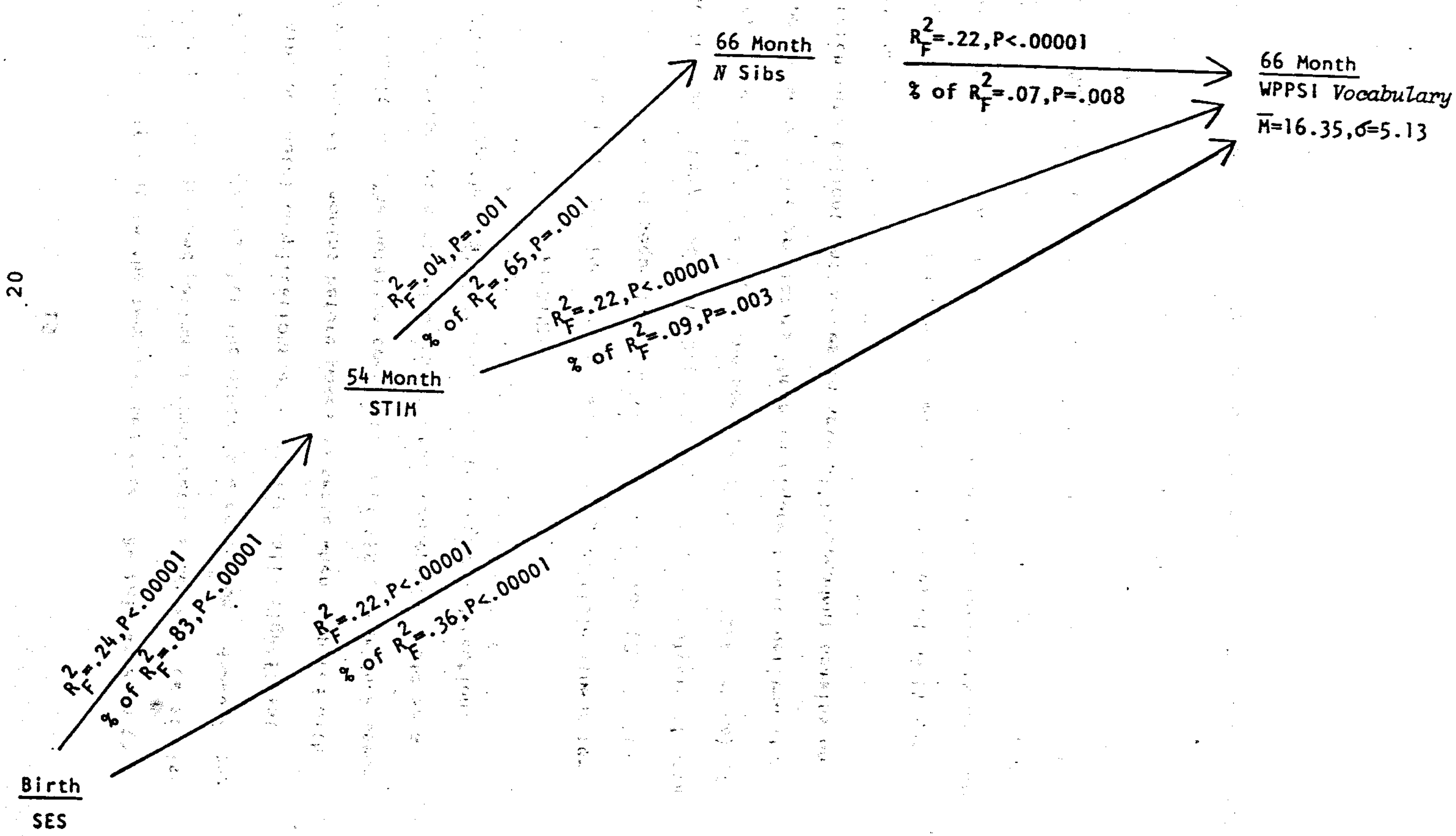
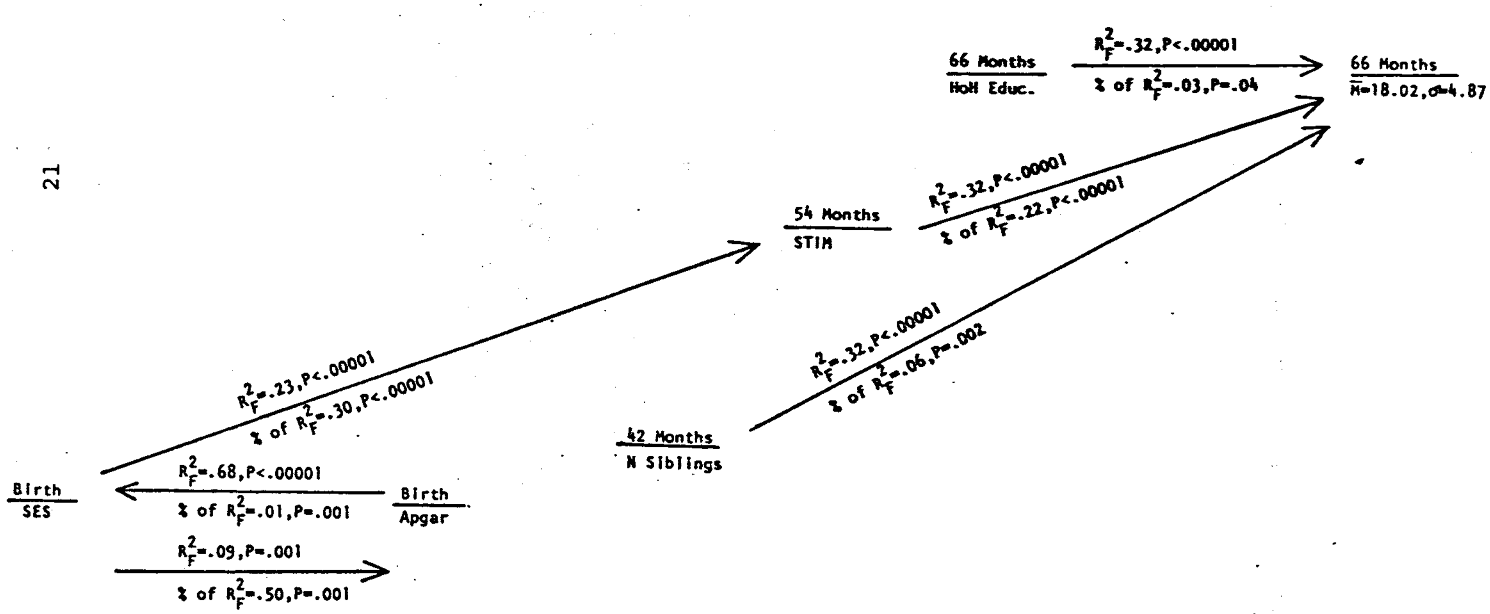


FIGURE 3

TSAR SCHEMA OF PREDICTORS AT BIRTH, 42, 54, AND 66 MONTHS,

AND 66 MONTH ITPA *Auditory Association* SCORES (N=256)



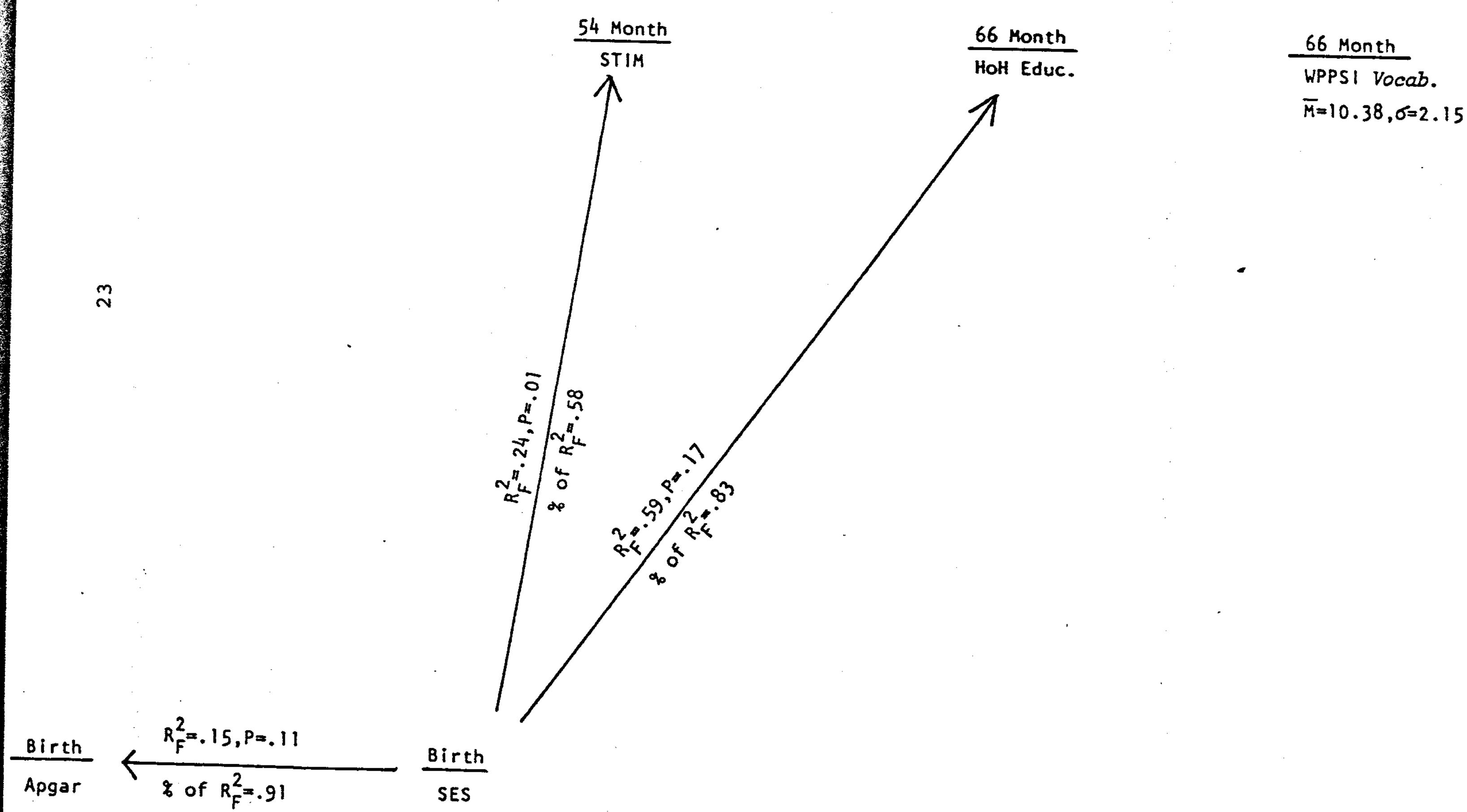
several things. There is a sequential link from perinatal SES score through 54 month STIM (Caldwell, 1970) and the number of sibs at 66 months to the criterion. This schema also shows both direct and indirect links as SES also connects directly to the criterion.

In Figure 3 we see two anomalies illustrated. In the perinatal data we see a two-way statistically significant link between Apgar and SES scores. Of these two mathematically correct findings only one is conceptually valid, since physiological conditions of an infant in the first few minutes of life, the Apgar score, cannot influence an SES score based on parental characteristics. The second anomaly is that we can trace a link backwards from the criterion to a 66 month variable, the educational level of the head of the household, but we can not go back any further since the linkage breaks off. At the same time there are two other antecedents, the 54 and 42 month variables, which go back in the developmental sequence to birth SES score.

In Figure 4's TSAR schema of five predictors we see that four of the predictors can be linked to each other; the only predictor variable not arrayed in Figure 4 is a 42 month variable, number of siblings. More importantly, we see that the schema links predictors, but the set does not connect to the criterion. In this case we see linkages which extend from birth to age 66 months. However, there is no link from any of the predictors in the schema to the criterion. The constellation of four predictors from perinatal Apgar score to education of the head of the household at sixty six months hinges on the perinatal McGuire and White (1955) SES score. However, there is no linkage from the perinatal SES score to the WPPSI *Vocabulary* scores of children selected because of their low scores on Raven's (1950) Colored Progressive Matrices (1947). The practical import of this is that the developmental influences we have seen

FIGURE 4

TSAR SCHEMA OF PREDICTORS AT BIRTH, 42, 54, and 66 MONTHS, AND 66 MONTH WPPSI *Vocabulary* SCORES-LOW GROUP (N=49)



in the previous three schemas continue to cluster among themselves, but have no functional relationship severally or collectively, to the criterion scores of the children.

The examples given so far use clinical data from child development. A parallel example is given in Figure 5; it uses data on social conditions surrounding childhood in fifty six countries and employs 1975 gross national products in United States dollars as the criterion. We provide this analysis of data from a work in progress (Jordan, 1981b) in order to show that economic and social data which have a temporal-sequential flavor can also be explicated in a fashion which is schematic, and which makes use of inferential tests of statistical significance.

DISCUSSION

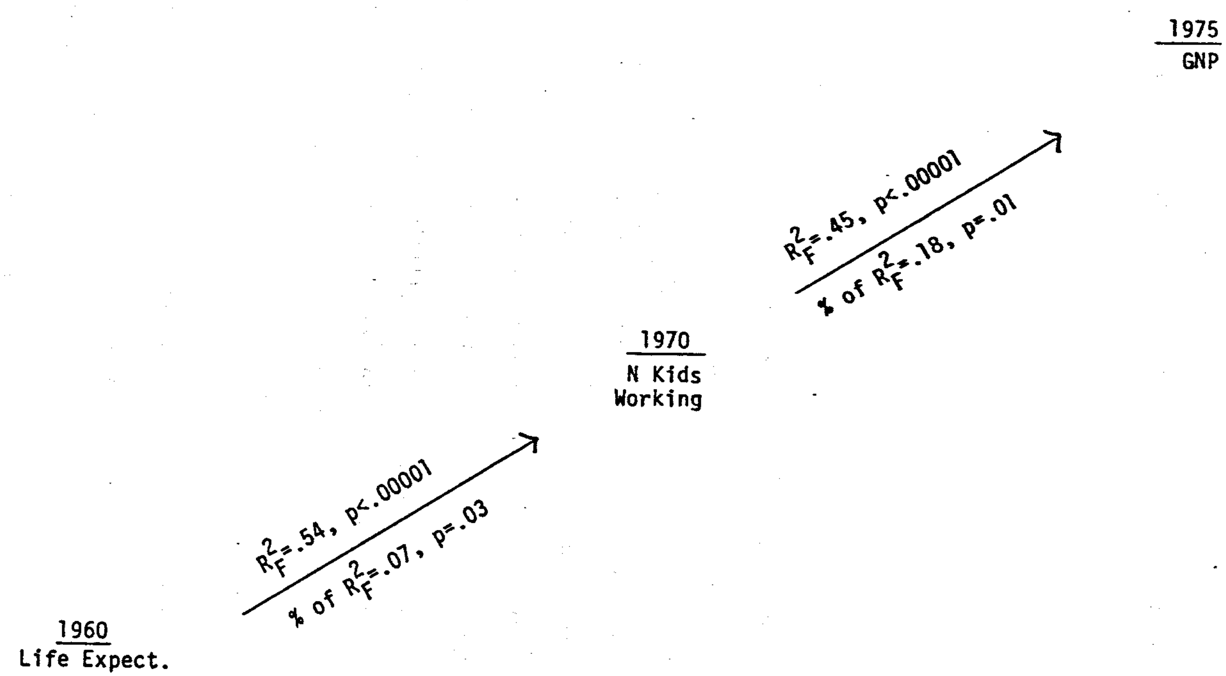
The TSAR schemas are based in regression analysis and it is important to note that only statistically significant variables and their contribution in full regression models is reported. $R^2$ values of the full models ($R_F^2$) vary a great deal in size; this is in contrast to uniformly low $R^2$ values in models whose criteria are measures of early development (Jordan, 1980).

The TSAR arrangement of data can be applied to any number of predictor variables. The computational and model-building aspect of the regression analysis can be handled by any regression package. In the examples given here the data were analyzed in models in which all predictors were treated as criteria in the presence of the other predictors as co-variables, which is the usual arrangement in multiple linear regression analysis. It is helpful to recall that a number of such combinations could violate the canon of logical order in temporal sequence, with the predictor occurring later in the developmental sequence. At that point the theory guiding selection of variables and their hypothetical relations limits analysis to regression models which are logical and

FIGURE 5

TSAR SCHEMA OF ENVIRONMENTAL INFLUENCES ON $ GNP

IN 56 POOR COUNTRIES



LTIPLE LINEAR REGRESSION VIEWPOINTS
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# BUDGET ALLOCATIONS AT MSU: LINEAR REGRESSION POLICY CAPTURING ANALYSIS

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ODUCTION:

Within higher education circles, the 1960's are already being wistfully re- ed to as the "golden decade". During these halcyon years the major problem ng most established universities was how to take advantage of the available to achieve maximum growth. MSU was no exception to this phenomenon. The cupation with growth left little room for concerns about efficiency, and was reflected in the University's management style. Ample funds relieved al administrators of the need to make hard allocation decisions. At MSU, nly requirement placed on departments and colleges by the Provost was one of ding him with a general account of what they were doing. The format of this al report" was left completely open and the units typically used this oppor- y to portray their accomplishments and lever for more funds by hinting at achievements were just around the corner. With the start of the 1970's, con- ned budgets suddenly materialized. The economic problems that plagued nation-

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refereed by editorial staff

al and state governments alike put the large, state supported, research oriented universities under a double loss as both state appropriations and federally-sponsored research funds began to lag. At MSU it became immediately obvious that the annual report provided neither the information nor the mechanism by which the Provost could make allocation decisions. This situation provided the impetus to develop a university-wide system called the Annual Evaluation and Report (AER), which combined the functions of program evaluation, academic planning, unit budgeting, and fund allocation.

THE PROBLEM:

Under the AER process, the allocation of new funds was procedurally dependent upon the results of a very detailed analysis of unit, department, and college data. Obviously, no allocation process can operate totally on quantitative data and so the admission of highly subjective judgments into the allocation process was essential; however, the amount by which the subjective considerations offset the quantified information is not easily controlled or even determined. This then is the issue at hand. How closely have fund allocations followed the recommendations resulting only from an examination of hard data? Before taking this question on directly, it was necessary to take into consideration some artifacts of the AER procedure itself in order to develop a series of reasonable hypotheses.

PRELIMINARY CONSIDERATIONS

Although data pertaining to every academic unit are thoroughly analyzed, and judgments are made as to the need for further staffing and support, the final allocations from the Provost are not made on a department by department basis.

:er, the allocation decisions are made at the college level. In cases where the departments within a college are consistently high or consistently low eed for additional resources, the aggregation of these departmental judgments he college level will result in a similar, clear-cut indicator. However, the departmental needs and performances are widely divergent within one col-, the final allocation decision that can develop from a synthesis of such a d pattern is much more subjective and unpredictable. Another complexity of relations between departments and their colleges is the fact that although cations are made to the college on the basis of specific departmental needs, AER procedure does not restrict the dean's flexibility in reallocating funds is/her departments. Thus there is no mechanism to ensure that the departments ive the funds that central administrators intended for them.

Out of consideration of the above, what might have been our original question e., the degree of match between allocations to departments and departmental --now expands into a series of questions:

1) Over a period of 5 years how well can we predict department budget increases from the key data elements reflecting upon the operation of the department?

2) Does our predictive ability increase if we know what college a department belongs to?

3) How well are college budget increases predicted from the college level data?

4) Does there seem to be a halo effect associated with the allocation process, i.e., does knowledge of a unit's (department or college) previous year's allocation enhance the predictive power of the data?

METHOD:

McNeil, Kelly, and McNeil discuss policy capturing (pp. 405-419) as an application of multiple linear regression. The process involves seeking variables which correlate with the results of some decision making process. They present, by way of example, Christal's fable "Selecting a Harem", the point of which (stated far more amusingly in the original than here) is that if a characteristic adds to the ability to predict the decision, then it must have been considered in the making of the decision. We have, in the AER process, a clear set of decisions (change in budget) and a group of "characteristics" which were intended to be a part of the decision making process. We know beforehand the explicit components of the budgeting policy and procedure. From these known elements we can, by induction, make several assumptions regarding the patterns by using regression techniques. Each of the four questions calls for some statistical evidence that the known elements of the budget policy have the effects which should most obviously occur. Our intention was to adopt the McNeil, Kelly, McNeil-Christal approach to this situation by referencing each question in terms of a full and restricted model to determine to what degree (if any) available information influenced the decision makers.

Seventy-two departments fit our criteria for complete data. We knew from the start that it could be difficult to find statistical significance for a small sample with large numbers of predictors. Indeed, we were aware as we started that at least one model would require that we use an N of 12, the number of colleges in our study. Since there was no way to increase the sample size (it was, save for departments and colleges deleted to eliminate reporting inconsistencies, the same as the population), it seemed reasonable (meaning that we saw no alternative) to approach significance from the view of replication: "The proof is always in the prediction; and whether or not a finding from a small sample has meaning rests in empirical replication" (McNeil, Kelly, and McNeil, p. 352). We felt that our sets of annual data allowed for a kind of replication. If certain variables accounted for a large amount of $R^2$ in every year, and if the total $R^2$ was consistent, then we might claim to have at least trailed and treed the policy if not exactly to have captured it. (Trailed = $R^2$ .25, Treed = $R^2f$ .50, Captured = $R^2$ over 75, by unilateral and rather arbitrary definition.)

Statistics were calculated by program REGRAN, a routine in the Veldman Library. It contrasts full and restricted models through the calculation of $F = \frac{(R^2f - R^2r)/dfn}{(1 - R^2f)/dfd}$. The first column of Table 5 was calculated on SPSS because of the need to transform variables, an option we have not yet had time to build into Veldman.

The next two sections describe the details of the variables and the hypotheses used to answer each of the four policy questions.

THE MODEL VARIABLES:

Dependent Variables:

$B_i(t)$ = Unit's budget change, from your (t-1) to year t, expressed as a percentage of the total budget.

i = 1 for the model using departments as the units (hypotheses 1, 2, 4).

i = 2 for the model using colleges as the units (hypotheses 3, 4).

Independent Variables

$E_i(t)$ = Department enrollment change measured in Student Credit Hours (SCH).

$EP_i(t)$ = Department's enrollment change expressed as a percentage.

$R_i(t)$ = Outside grant and contract research funds attracted by the department.

$RF_i(t)$ = Outside grant and contract research funds per full time equivalent faculty (FTE) member in the department.

$P_i(t)$ = Department's published outputs per FTE.

$AAU_i(t)$ = Department's SCH/FTE workoad compared to AAU departments average workload. The comparison is expressed in terms of % change in faculty staff needed to match the AAU workloads.

$PBES_i(t)$ = Department's SCH/FTE workload compared to similar MSU departments average workloads in a manner identical to AAU(t).

$COL_k(t)$ = Membership variable indicating to which of the twelve colleges the department belongs. K = 1, 2, .... 11.

THE HYPOTHESES:

Hypothesis 1a, b, c, d, e: For each of the five budget years, certain AER variables are significant predictors of annual department budget change.

Full Model: $B_1(t) = A_0U + C_1E_1(t) + C_2W_1(t) + C_3R_1(t) + C_4RF_1(t) + C5SP_1(t) + C_6EP_1(t) + C_7AAU_1(t) + C_8PBES_1(t) + E$

Restricted Model: $B_1(t) = A_0U(t) + E$ $\quad t = 1, 2, 3, 4$

(Models 1, b, c, d, e, related to years t + 1(FY 1976), ... , 5 (FY 1980)

Hypothesis 2a, b, c, d, e: College membership is a significant predictor of annual department budget change over and above the effects of the AER variables.

Full Model: $B_1(t) = A_0U(t) + \ldots + C_8PBES_1(t) + D_kCol_k(t) + E$

$k = 1, \ldots, 11$

Restricted Model: $B_1(t) = A_0U\ (t) + \ldots + C_8PBES_1(t) + E$

$t = 1, \ldots, 5$

Hypothesis 3a, b, c, d, e: A subset of the predictors in Hypothesis 1 will significantly predict change in the college budget (given year).

Full Model: $B_2(t) = A_0U(t) + C_1E_2(t) + C_2W_2(t) + C_3R_2(t) + E$

Restricted Model: $B_2(t) = A_0U(t) + E$ $\quad t = 1, \ldots, 5$

Hypothesis 4a, b, c, d: The previous years' departmental budget changes are significant predictors of annual department budget change.

Department

Full Model: $B_1(t) = A_0U + C_1B_1(t-1)$

Restricted Model: $B_1(t) = A_0U\ (t)$ $\quad t = 2, 3, 4, 5$

College

Full Model: $B_2(t) = A_0U(t) - C_1B_2(t-1) + E$

Restricted Model: $B_2(t) = A_0U(t) + E$

## Results

Table 1
Hypothesis 1
(8 Basic Predictors)

| Year | $R^2$ Full | $R^2$ Restricted | F | P | dfn | dfd |
|---|---|---|---|---|---|---|
| 1974 | .0838 | .00 | .721 | .6741 | 8 | 63 |
| 1975 | .1611 | .00 | 1.512 | .1707 | 8 | 63 |
| 1976 | .1931 | .00 | 1.884 | .0778 | 8 | 63 |
| 1977 | .0502 | .00 | .416 | .9071 | 8 | 63 |
| 1978 | .2178 | .00 | 2.192 | .0394 | 8 | 63 |

Table 2
Hypothesis 2
(College Over and Above 8 Basic Predictors)

| Year | $R^2$ Full | $R^2$ Restricted | F | P | dfn | dfd |
|---|---|---|---|---|---|---|
| 1974 | .2897 | .0838 | 1.372 | .2140 | 11 | 52 |
| 1975 | .4110 | .1611 | 2.006 | .0463 | 11 | 52 |
| 1976 | .2410 | .1931 | 1.299 | .9828 | 11 | 52 |
| 1977 | .4385 | .0502 | 3.270 | .0021 | 11 | 52 |
| 1978 | .3352 | .2178 | .835 | .6076 | 11 | 52 |

Table 3
Hypothesis 3
College Level Data
Budget with Outside Dollars, Student Credit Hours, Enrollment as Predictors

| Year | $R^2$ Full | $R^2$ Restricted | F | P | dfn | dfd |
|---|---|---|---|---|---|---|
| 1974 | .4086 | .00 | 1.612 | .2707 | 3 | 8 |
| 1975 | .2843 | .00 | .927 | .5223 | 3 | 8 |
| 1976 | .6388 | .00 | 4.127 | .0559 | 3 | 8 |
| 1977 | .1943 | .00 | .563 | .6589 | 3 | 8 |
| 1978 | .2537 | .00 | .793 | .5369 | 3 | 8 |

Table 4
4a
Hypothesis 4
(Previous Budget Change - Department)

| Year/ Predicted by | $R^2$ Full | $R^2$ Restricted | F | P | dfn | dfd |
|---|---|---|---|---|---|---|
| 1978 by Prev. 4 | .0990 | .00 | 1.868 | .1252 | 1 | 68 |
| 1978 by 1977 | .0074 | .00 | .521 | .5202 | 1 | 70 |
| 1977 by 1976 | .0083 | .00 | .584 | .5464 | 1 | 70 |
| 1976 by 1975 | .0075 | .00 | .532 | .5249 | 1 | 70 |
| 1975 by 1974 | .0139 | .00 | .985 | .6746 | 1 | 70 |

4b
(Effect of Previous Budget Change - College)

| Year/ Predicted by | $R^2$ Full | $R^2$ Restricted | F | P | dfn | dfd |
|---|---|---|---|---|---|---|
| 1978 by Prev. 4 | .2621 | .00 | .533 | .7190 | 4 | 6 |
| 1978 by 1977 | .2238 | .00 | 2.595 | .1392 | 1 | 9 |
| 1977 by 1976 | .0988 | .00 | .987 | .6518 | 1 | 9 |
| 1976 by 1975 | .1057 | .00 | 1.063 | .3307 | 1 | 9 |
| 1975 by 1974 | .0933 | .00 | .926 | .6366 | 1 | 9 |

**DISCUSSION:**

Variance accounted for by the eight predictors is fairly small, about 20% in the year it is largest (1976) (Table 1). We were concerned that this seemed to suggest that very little of the decision was based on the data. This concern lead to some manipulations which we shall describe further on and the "College over and above" hypothesis. In 1976 and 1978 the variance accounted for may be considered

Variance accounted for by college membership in addition to the other variables ranges from 28 to 44%, a considerable improvement (Table 2). F probabilities in 1975 and 1977 are .0463 and .0021, respectively, which adds to the credibility of the pattern. The suggestion of these hypotheses seems to be that a department is more dependent on its collegiate affiliation than on its departmental merits in certain years. To some degree, experience and the data tell us that this is true. Inspection of weighting coefficients identified exactly those colleges which have received large budget increases because of very heavy enrollment demands. Apparently, in a given year, such conditions reduce the Provost's flexibility and leave less money to be distributed through the rest of the system. The most extreme form of the result would be the low productivity department in a high budget college receiving extra funds simply because they are available to the dean and the high productivity department in a college which is not at the positive end of the need cycle receiving a very small, or no, increase as the dean attempts to stretch the resources around his or her units.

The low $R^2$'s for 1a through 1e motivated us to also build a model using curvilinear relationships. Using the ten most commonly recurring predictors, linear and curvilinear, across the five years as the predictors produced results which were not all that different from those obtained in 1a through 1e (Table 5). This would again seem to indicate that the department is often not the focal unit in this process.

Table 5

| Year | 10 Modified $R^2$ | 8 Original $R^2$ |
|---|---|---|
| 1974 | .13445 | .0838 |
| 1975 | .11023 | .1611 |
| 1976 | .24694 | .1931 |
| 1977 | .10332 | .0502 |
| 1978 | .20089 | .2178 |

Perhaps another point to consider is that it is likely that central administrators suffer from such intense information overload that they are forced to make their decisions on the basis of data aggregated in the most concise manner and to assume that deans will distribute funds in the most meaningful way. A promising route for future study would be to attempt to capture deans' policies.

The number of colleges was too small to allow us to test the hypothesis that the eight basic predictors aggregated at the college level accounted for larger amounts of variance than when aggregated at the department level (a fairly obvious corollary of the previous hypotheses). To test for the general idea, we chose three variables which appeared to be heavy contributors (outside dollars, student credit hours, enrollment) (Table 3); the results showed that even this small number of predictors accounted for fairly large proportions of variance at the collegiate level, which tends to confirm the previous results relative to collegiate influence and the role of the college in the decision making process.

Table 4 shows the results of tests to determine the "carry over" or "halo" effects of budget changes to subsequent years. Probabilities are very low; however, the patterns are consistent with the other results: little predictability at the department level, more at the collegiate level.

No one should be totally surprised that provosts or other budget level officials are forced by the complexity of their tasks to focus their decisions at the highest level possible. These findings may, however, confirm the suspicions and feelings of many department chairs that they are at the mercy of forces outside their control.

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# EVALUATING TITLE I EARLY CHILDHOOD PROGRAMS: PROBLEMS, THE APPLICABILITY OF MODEL C, AND SEVERAL EVALUATION PLANS

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The enactment of the 1974 amendments to Title I expresses the growing concern for developing adequate evaluation strategies for assessing the effectiveness of Title I programs. The current Title I Evaluation and Reporting System (TIERS) was designed for use in grades 2-12. However, Title I programs are also present in the early childhood grades (prekindergarten, kindergarten, and first grade). Huron Institute is currently investigating alternative evaluation strategies to assess Title I programs in these grade levels (Bryk, Strenie, and Weisberg, 1979).

Although many evaluation models exist for evaluating early childhood programs, this paper will focus on the "Special Regression Model," Model C in the TIERS. We first present factors which make evaluating early childhood programs particularly difficult. The paper concludes with several feasible evaluation plans utilizing Model C.

## Factors Which Make Evaluating Early Childhood Programs Difficult

Several factors make assessing the effectiveness of Title I early childhood programs more difficult than in the upper grades. Factors that contribute to this difficulty include: 1) Scope of Programs, 2) Instrumentation for Early Childhood, 3) Developmental Characteristics of Early Childhood, and 4) Student Selection.

Scope of programs. The scope and content of early childhood programs vary widely across programs. Some of the variation is a result of grade levels. Most prekindergarten programs are global in nature, placing the greatest emphasis on early intervention and exposure to the school environment. Parental involvement in the students' education is also stressed. In contrast, kindergarten programs emphasize readiness skills: prereading, mathematics, language, and socio-emotional development. First grade programs begin to approximate programs found in upper grade Title I programs, by concentrating on supplementing regular school programs and bolstering the readiness skills taught in kindergarten.

Instrumentation. Serious concern has been voiced regarding the technical excellence of early childhood measures. The majority of measures do not meet minimum standards for validity, reliability and appropriateness of norms (Hoephner, Stern, and Nummedal, 1973). Measures which meet minimum criteria are of a cognitive nature, the majority being "IQ" type instruments. In many instances, these instruments are inappropriate measures of the goals and objectives of Title I programs. Furthermore, cognitive growth is so rapid at this age level that it cannot be measured, pre and post, by most instruments.

Developmental Characteristics. Young children have minimal experience in formal assessment situations. As a result, many of the prerequisite skills for test taking are lacking. In addition, egocentricity, emotional reactivity, and fluctuations in attention span may influence performance on assessment instru-

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ments. Therefore, scores obtained from these instruments may not accurately measure the student's achievement level in the content area. Other assessment techniques may be needed to measure the student's achievement.

Student Selection. The last factor which contributes to the difficulty in assessing the effectiveness of Title I programs is student selection. Because instrumentation is problematic, test scores used as the sole criteria for selection, may identify many students as needing the program, when in fact some students do not. Likewise, many students are identified as not needing the program, when in fact some of those students do. Thus, the selection of the appropriate students is problematic. The design one chooses to evaluate the early childhood program must avoid this hazard, as well as deal with the previously mentioned factors.

## The Special Regression Model -- Model C

The Special Regression Model (Model C) is a form of the regression projection model proposed by Campbell and Stanley (1963). The remarks in this paper actually pertain to Model C1, the "norm-referenced version of Model C" (referred to as Model C in this paper-see Tallmadge and Wood for complete discussion of the models). Many of the remarks do not apply to Model C2, the Model which uses a non-normed test for posttest. Expected posttest performance of the Title I group is based on the projection of the regression line from the comparison group. (See Figure 1.) If the Title I program is not effective, over and above the regular program, then the Title I effect will be zero. If the Title I program is effective, then the performance of the Title I students will be higher than predicted from the comparison group. Model C requires that all students in grades served by Title I in a target school be tested, and that the students who score lowest on the pretest be placed in the Title I program with the remaining students serving as comparison students. The cutoff would be based on the number of students that can be served, and ideally would be the same in all buildings in a school district. Actually, the pretest/selection measure may be achievement test scores, independently made teacher ratings, classroom grades, or some combination of these or other types of measures.

Reasons for Using Model C

The first major reason for using Model C is the fact that students learn quite rapidly in the early years of schooling. This very often necessitates the use of a different test at posttest time than that used at pretest time. Model C allows for the use of a different test at the two sessions.

Secondly, selecting students for the Title I program in these early years can be difficult. Since most testing must be accomplished individually, testing takes a lot of time, it is usually very costly, and there are very few good screening devices available. In addition, the longer the screening takes, the less time there is for instruction. Because Model C uses the pretest as the selection device, Model C is preferable over other Title I evaluation Models which require that pretest and selection be separate. Because it is difficult to get one good screening device, it would be an additional burden to get another device which could be used as the pretest. Model C does not require two procedures for student selection and pretest, but requires that student selection be based on the pretest.

A third advantage of Model C is that it does not make any assumptions about the effectiveness of the regular program. Indeed many schools are not as effective with their regular curriculum as the average curriculum in the country. Because Model C uses the actual results from students in the regular program, it yields an accurate indication of the Title I effect, over and above the regular program, in a particular school.

Fourthly, the procedure used for pretest/selection in Model C does not have to be a norm-referenced test. Therefore, teacher judgements, norm-referenced tests, or non-norm referenced tests could be used individually, or as part of a composite score. A composite score would most likely identify more accurately the students who are most in need of additional educational services. One way in which some Title I programs are implementing Model C is to use a non-norm referenced test at pretest, and a norm-referenced test at posttest. The pretest ranks students for student selection and provides diagnostic/prescriptive information in terms of the kinds of skills the students lack. Thus posttest norm-referenced cutoff situation have pretest scores below some Title I students. Thus, there is a wider range in the comparison group over which the regression slope is determined.

## Model C Evaluation Plans

Figure 2 contains three possible evaluation plans using Model C. For each plan, the testing time, test, and purpose of test are identified. For instance, those interested in testing only every Spring would find evaluation plan 2 appropriate. Since it would be unlikely that a pre-kindergarten spring score would be available, the kindergarten evaluation would probably have to be a Fall-Spring evaluation. But the kindergarten Spring score could also be used for the pretest for the grade 1 evaluation.

Figure 2 indicates that evaluation plans 1 and 2 both result in once a year testing. One should also note that the test used at any testing time may be the same as previously used, or a different test.

Summary

Because the purpose of Title I evaluation is to determine the effect of Title I over and above the regular curriculum, Model C seems most appropriate. The advantages of the Special Regression Model (Model C) for early childhood evaluation seem to outweigh the disadvantages. Those advantages are:

- Scope of Program - Model C allows for the use of a different test at posttest than used at pretest
- Instrumentation - non-norm referenced test can be administered at pre-test, providing diagnostic and prescriptive information as well as baseline and student selection information
- Developmental Characteristics - Different test levels can be used pre and post, even if they are not linked by a common scale
- Student selection - a separate selection/pretest is not needed <u>and</u> the selection/pretest can be a composite score

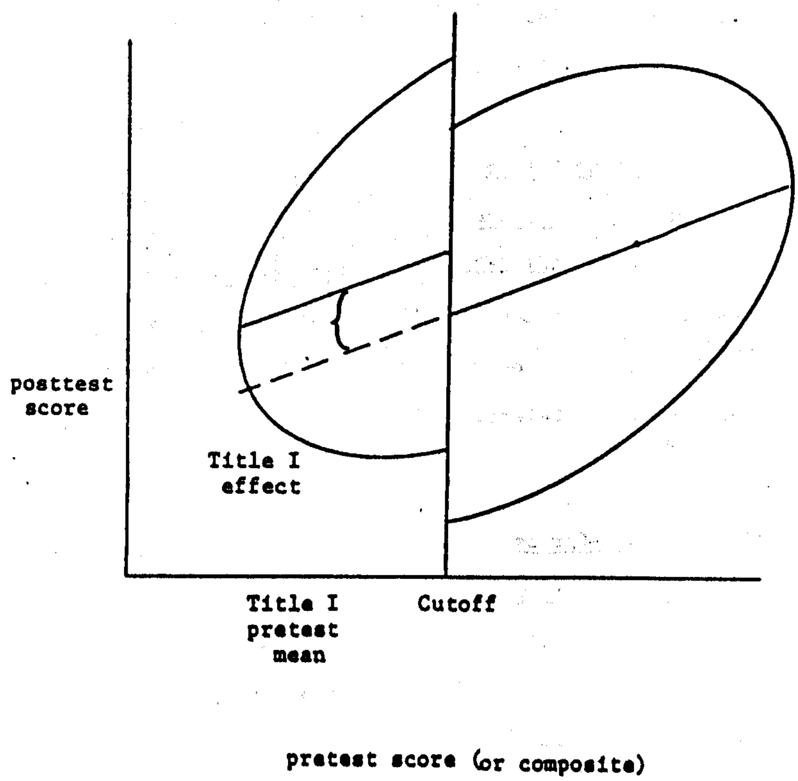


Figure 1. Model C approach to determining Title I effect

**Evaluation Plan # 1 - - - Fall-Fall**

| Testing Time | Test | Purpose | Evaluation of K | Grade 1 | Grade 2 |
|---|---|---|---|---|---|
| Fall of K | A | Selection (K) | pre (K) | | |
| Fall of 1 | A or B | Selection (1) | post (K) | pre (1) | |
| Fall of 2 | A or B or C | Selection (2) | | post (1) | pre (2) |

**Evaluation Plan #2 - - - Spring-Spring**

| Testing Time | Test | Purpose | K | Grade 1 | Grade 2 |
|---|---|---|---|---|---|
| Fall of K | A | Selection (K) | pre (K) | | |
| Spring of K | A or B | Selection (1) | post (K) | pre (1) | |
| Spring of 1 | A or B or C | Selection (2) | | post (1) | pre (2) |
| Spring of 2 | A or B or C or D | Selection (3) | | | post (2) |

**Evaluation Plan #3 - - - Fall-Spring**

| Testing Time | Test | Purpose | K | Grade 1 | Grade 2 |
|---|---|---|---|---|---|
| Fall of K | A | Selection (K) | pre (K) | | |
| Spring of K | A or B | | post (K) | | |
| Fall of 1 | A or B or C | Selection (1) | | pre (1) | |
| Spring of 1 | A or B or C or D | | | post (1) | |
| Fall of 2 | A or B or C or D or E | Selection (2) | | | pre (2) |
| Spring of 2 | A or B or C or D or E or F | | | | post (2) |

Figure 2. Model C evaluation plans for early childhood programs

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# AN ESTIMATE OF POWER FOR INTACT GROUPS AND FOR INDIVIDUAL SUBJECTS: A NOTE

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The problem of intact groups has been clearly delineated in a variety of texts and papers (Campbell and Stanley, 1962; Kerlinger, 1973; Newman and Newman, 1978; Poynor, 1977; etc.). Cohen (1977) has popularized the concept and importance of power for the applied practitioner. In calculating power, one has to consider four parameters: alpha ($\alpha$), N size (N), effect size ($f^2$), and power (P).

## ALPHA

Alpha is the probability of making a Type I error. It is generally set of .05, .01, or .001. If one has no other reason, traditionally in educational research, alpha is set at .05 for a two-tailed test.

## EFFECT SIZE

Effect size can be thought of conceptually as how far the means of two groups are apart in terms of standard deviation units (i.e., one standard deviation, 1/2 standard deviation, etc.). Another way of looking at it is in terms of $r^2$

(proportion of variance accounted for). For example, is 5% being accounted for, is 30% being accounted for, etc. Cohen (1977) uses $f^2$ to represent effect size. He subjectively defines three effect sizes: large (.35), medium (.15), and small (.02).

Effect size in reality is subjectively set depending on how well you know your area and what you are looking for. Effect size that is large in one instance may be small in another. Cohen's guidelines are subjective examples.

POWER

Power is defined as (1 - probability of making a Type II error). Another way of saying this is that power is the probability of detecting a difference when a difference exists. For example, if the power of a test is .76, this means that 76 times out of 100 the statistical procedures will be capable of detecting the relationship if it exists.

N SIZE

N is the total number of subjects used in the study.

CALCULATING POWER FOR INDIVIDUALS

The following formulas are used to calculate power:

$$L = f^2 v$$

where: $v = df_2 = (N - m_1)$

$u = df_1 = (m_1 - m_2)$

u is needed to enter the table. The two values needed to enter the table are L and u. Alpha helps you determine which table to enter.

The following is an example.

Let's assume we have one hundred subjects (N = 100). We want to be able to detect a medium size effect ($f^2$ = .15). Let's assume we have ten linearly independent variables that includes the unit vector. We're interested in asking the following question. Do these ten variables account for a significant amount of variance in the criterion over and above no information? Let's assume our alpha level is set at .01. We now can determine power.

The first step is to solve for L. $l = f^2 v$. Since $v = df_2$, which is $(N - m_1)$, or (100 - 10), then v = 90.. And $F^2$ = .15. Then, L = (.15) (90) = 13.5. Alpha is equal to .01. u is equal to $df_1$ or $(m_1 - m_2)$ = (10 - 1) = 9*. Therefore, we have:

L = 13.5

u = 9

$\alpha$ = .01

Since alpha = .01, we would use Cohen's Table 9.3.1. We enter it at a u of 9. We look for an L value of 13.5. This would fall between L values of 12 and 14, or an estimated power of 49.5

*Newman, I. and Thomas, J., "A Note on the Calculation of Degrees of Freedom for Power Analysis using Multiple Linear Regression Models." Multiple Linear Regression Viewpoints, 1979, 9, 53-58.

If we are interested in doing this same problem at an alpha of .05, we would use Cohen's Table 9.3.2. Look at u = 9, L = between 12 and 14, we have an estimated power of 72. We can see that as alpha becomes less stringent, the power increases.

SOLVING FOR N

Given the same research question, in this case we are interested in determining N size. Given the following, then:

alpha = .01

$f^2$ = .02 (small effect size)

We subjectively set power equal to .80. (Cohen recommends a power of .80 if no other information is given. This is comparable rationale to setting alpha equal to .05).

The formula we now use is:

$$N = \frac{L}{f^2} + u + m_2$$

To determine the L size for an alpha of .05, we use Cohen's Table 9.4.2. We enter the table for a given power and a particular u. Since power is set at .80 and u is 9, our L = 15.65. Using the above formula, we solve for N.

$$N = \frac{15.65}{.02} + 9 + 1$$

$$N = 792.5$$

The suggestion is, that whenever you are solving for N and you get a decimal, you always round upwards, so N would be equal to 1082.

## CALCULATING POWER FOR INTACT GROUPS

If one wanted to use the intact group, on the other hand, as the unit of analysis instead of the individual subject, a problem arises.

When the researcher has a group of five, the N is 1 for intact group analysis. When the number in the group is ten, the N is 1, and then the number in the group is twenty-five, the N is 1. A problem occurs because stability of scores varies from a group of five to a group of twenty-five. This has implications for power analysis.

A key underlying consideration in any analysis is the determination of the independent unit of analysis. When one analyzes individuals, the assumption is that each subject is performing independently of any other subject. The unit of analysis is the subject. However, when one analyzes subjects in a classroom setting or therapy groups, it is unlikely in most situations that the individual performance is independent of others in that group. The unit of analysis in this case, then, is the group.

In considering power analysis, it is important to be aware of the conditional effects on the decision to analyze subjects or groups. The research design will usually determine the unit of analysis. The power analysis, then, must be consistent with that unit of analysis.

Under certain conditions, analyzing individual subjects may result in more power due to the larger N for subjects than groups. In other conditions, analyzing groups instead of individuals results in a smaller N, but may give greater power due to the decrease in variability. A study by Malinke (1980) illustrates this difference. Data was analyzed both as from separate subjects and as from intact groups. More statistical significances were found when the intact group was the unit of analysis.

Barcikowski (1980) is one of the few researchers who has addressed the analyses and estimations of power for group means for different numbers of subjects in groups and different effect sizes. When the researcher uses the suggested effect sizes of .02 (small effect size), .15 (medium effect size), and .35 (large effect size) as suggested by Cohen (1977); also discussed by Newman and Benz, 1979) one can use the tables developed by Barcikowski and estimate what the power will be for alpha levels of .01, .05, .10 when the number of subjects in each group is either 1, 10, 15, 20, 25, 30, 35, or 40, and when the population interclass correlation is .01 and .05.

As one can see from the considerable increase in power analysis emphasis in the last few years, and the value to such insight, it is evident that power analysis for intact groups must be an important consideration for researchers.

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## TABLE 9.3.1

### POWER AS A FUNCTION OF L AND u AT a = .01

| u | L: 2.00 | 4.00 | 6.00 | 8.00 | 10.00 | 12.00 | 14.00 | 16.00 | 18.00 | 20.00 | 25.00 | 30.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 28 | 45 | 60 | 72 | 81 | 88 | 92 | 95 | 97 | 99 | * |
| 2 | 08 | 20 | 35 | 49 | 61 | 72 | 80 | 87 | 91 | 94 | 98 | 99 |
| 3 | 07 | 16 | 29 | 42 | 54 | 65 | 74 | 82 | 87 | 91 | 97 | 99 |
| 4 | 06 | 14 | 25 | 37 | 49 | 60 | 69 | 77 | 84 | 89 | 96 | 98 |
| 5 | 05 | 12 | 22 | 33 | 44 | 55 | 65 | 74 | 80 | 86 | 94 | 98 |
| 6 | 05 | 11 | 19 | 30 | 41 | 51 | 61 | 70 | 77 | 83 | 93 | 97 |
| 7 | 04 | 10 | 18 | 27 | 37 | 48 | 58 | 67 | 74 | 81 | 91 | 96 |
| 8 | 04 | 09 | 16 | 25 | 35 | 45 | 55 | 64 | 72 | 78 | 90 | 96 |
| 9 | 04 | 08 | 15 | 23 | 33 | 42 | 52 | 61 | 69 | 76 | 88 | 95 |
| 10 | 03 | 08 | 14 | 22 | 31 | 40 | 49 | 58 | 66 | 74 | 87 | 94 |
| 11 | 03 | 07 | 13 | 20 | 29 | 38 | 47 | 56 | 64 | 71 | 85 | 93 |
| 12 | 03 | 07 | 12 | 19 | 27 | 36 | 45 | 54 | 62 | 69 | 83 | 92 |
| 13 | 03 | 06 | 12 | 18 | 26 | 34 | 43 | 52 | 60 | 67 | 82 | 91 |
| 14 | 03 | 06 | 11 | 17 | 25 | 33 | 41 | 50 | 58 | 65 | 80 | 90 |
| 15 | 03 | 06 | 10 | 16 | 23 | 31 | 40 | 48 | 56 | 64 | 79 | 89 |
| 16 | 03 | 06 | 10 | 16 | 22 | 30 | 38 | 46 | 54 | 62 | 77 | 89 |
| 20 | 02 | 05 | 08 | 13 | 19 | 26 | 33 | 41 | 48 | 56 | 72 | 84 |
| 24 | 02 | 04 | 07 | 12 | 17 | 22 | 29 | 36 | 43 | 51 | 67 | 80 |
| 28 | 02 | 04 | 07 | 10 | 15 | 20 | 26 | 32 | 39 | 46 | 62 | 76 |
| 32 | 02 | 04 | 06 | 09 | 13 | 18 | 22 | 29 | 32 | 42 | 58 | 72 |
| 40 | 02 | 03 | 05 | 08 | 11 | 15 | 20 | 25 | 30 | 36 | 51 | 65 |
| 50 | 02 | 03 | 05 | 07 | 09 | 13 | 16 | 21 | 25 | 31 | 44 | 58 |
| 60 | 02 | 03 | 04 | 06 | 08 | 11 | 14 | 18 | 22 | 26 | 39 | 52 |
| 80 | 02 | 02 | 03 | 05 | 06 | 09 | 11 | 14 | 17 | 21 | 31 | 43 |
| 100 | 01 | 02 | 03 | 04 | 06 | 07 | 09 | 11 | 14 | 17 | 26 | 36 |

* Power greater than .995.

## TABLE 9.3.2

### POWER AS A FUNCTION OF L AND u AT a = .05

| u | L: 2.00 | 4.00 | 6.00 | 8.00 | 10.00 | 12.00 | 14.00 | 16.00 | 18.00 | 20.00 | 25.00 | 30.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 29 | 52 | 69 | 81 | 89 | 93 | 96 | 98 | 99 | 99 | * | * |
| 2 | 23 | 42 | 58 | 72 | 82 | 88 | 93 | 96 | 97 | 99 | * | * |
| 3 | 19 | 36 | 52 | 65 | 76 | 84 | 90 | 93 | 96 | 98 | 99 | * |
| 4 | 17 | 32 | 47 | 60 | 72 | 80 | 87 | 91 | 94 | 96 | 99 | * |
| 5 | 16 | 29 | 43 | 56 | 68 | 77 | 84 | 89 | 93 | 95 | 98 | * |
| 6 | 15 | 27 | 40 | 53 | 64 | 74 | 81 | 87 | 91 | 94 | 98 | 99 |
| 7 | 14 | 25 | 38 | 50 | 61 | 71 | 79 | 85 | 89 | 93 | 97 | 99 |
| 8 | 13 | 24 | 36 | 48 | 59 | 68 | 77 | 83 | 88 | 92 | 97 | 99 |
| 9 | 13 | 23 | 34 | 45 | 56 | 66 | 74 | 81 | 86 | 90 | 96 | 99 |
| 10 | 12 | 21 | 32 | 43 | 54 | 64 | 72 | 79 | 85 | 89 | 96 | 98 |
| 11 | 12 | 21 | 31 | 42 | 52 | 64 | 70 | 78 | 83 | 88 | 95 | 98 |
| 12 | 11 | 20 | 30 | 40 | 50 | 60 | 69 | 76 | 82 | 87 | 94 | 98 |
| 13 | 11 | 19 | 29 | 39 | 49 | 58 | 67 | 74 | 80 | 85 | 93 | 97 |
| 14 | 11 | 18 | 28 | 37 | 47 | 57 | 65 | 73 | 79 | 84 | 93 | 97 |
| 15 | 11 | 18 | 27 | 36 | 46 | 55 | 64 | 71 | 78 | 83 | 92 | 97 |
| 16 | 10 | 17 | 26 | 35 | 45 | 54 | 62 | 70 | 76 | 82 | 91 | 96 |
| 20 | 10 | 16 | 23 | 31 | 40 | 49 | 57 | 65 | 72 | 78 | 88 | 94 |
| 24 | 09 | 15 | 21 | 29 | 37 | 45 | 53 | 60 | 67 | 74 | 85 | 92 |
| 28 | 09 | 14 | 20 | 27 | 34 | 42 | 49 | 57 | 64 | 70 | 82 | 91 |
| 32 | 08 | 13 | 18 | 25 | 32 | 39 | 46 | 53 | 60 | 67 | 80 | 88 |
| 40 | 08 | 12 | 17 | 22 | 28 | 40 | 41 | 48 | 55 | 61 | 74 | 84 |
| 50 | 08 | 11 | 15 | 20 | 25 | 31 | 37 | 43 | 49 | 55 | 69 | 80 |
| 60 | 07 | 10 | 14 | 18 | 23 | 28 | 33 | 39 | 45 | 50 | 64 | 75 |
| 80 | 07 | 09 | 12 | 16 | 20 | 24 | 28 | 33 | 38 | 43 | 56 | 67 |
| 100 | 07 | 09 | 11 | 14 | 18 | 21 | 25 | 29 | 34 | 38 | 50 | 61 |

* Power greater than .995.

Note. From Statistical Power Analysis for the Behavioral Sciences by Jacob Cohen. New York: Academic Press Inc., 1977. Reprinted by permission.

## TABLE 9.3.3

### Power as a Function of L and u at a = .10

| u | L 2.00 | 4.00 | 6.00 | 8.00 | 10.00 | 12.00 | 14.00 | 16.00 | 18.00 | 20.00 | 25.00 | 30.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 41 | 64 | 79 | 88 | 94 | 97 | 98 | 99 | * | * | * | * |
| 2 | 33 | 54 | 70 | 81 | 89 | 93 | 96 | 98 | 99 | 99 | * | * |
| 3 | 30 | 48 | 64 | 76 | 85 | 90 | 94 | 97 | 98 | 99 | * | * |
| 4 | 27 | 44 | 60 | 72 | 81 | 88 | 92 | 95 | 97 | 98 | * | * |
| 5 | 25 | 41 | 56 | 69 | 78 | 85 | 90 | 94 | 96 | 98 | 99 | * |
| 6 | 24 | 39 | 53 | 66 | 75 | 83 | 89 | 92 | 95 | 97 | 99 | * |
| 7 | 23 | 37 | 51 | 63 | 73 | 81 | 87 | 91 | 94 | 96 | 99 | * |
| 8 | 22 | 35 | 49 | 61 | 71 | 79 | 85 | 90 | 93 | 95 | 98 | * |
| 9 | 21 | 34 | 47 | 58 | 69 | 77 | 84 | 88 | 92 | 95 | 98 | 99 |
| 10 | 20 | 33 | 45 | 57 | 67 | 75 | 82 | 87 | 91 | 94 | 98 | 99 |
| 11 | 20 | 31 | 43 | 55 | 65 | 74 | 80 | 86 | 90 | 93 | 97 | 99 |
| 12 | 19 | 31 | 42 | 53 | 63 | 72 | 79 | 85 | 89 | 92 | 97 | 99 |
| 13 | 19 | 30 | 41 | 52 | 62 | 70 | 78 | 84 | 88 | 92 | 97 | 99 |
| 14 | 19 | 29 | 40 | 50 | 60 | 69 | 76 | 82 | 87 | 91 | 96 | 99 |
| 15 | 18 | 28 | 39 | 49 | 59 | 68 | 75 | 81 | 86 | 90 | 96 | 98 |
| 16 | 18 | 28 | 38 | 48 | 58 | 66 | 74 | 80 | 85 | 89 | 95 | 98 |
| 20 | 17 | 26 | 35 | 44 | 53 | 62 | 70 | 76 | 82 | 86 | 93 | 97 |
| 24 | 16 | 24 | 32 | 41 | 50 | 58 | 66 | 72 | 78 | 83 | 92 | 96 |
| 28 | 16 | 23 | 31 | 39 | 47 | 55 | 62 | 69 | 75 | 80 | 90 | 95 |
| 32 | 15 | 22 | 29 | 37 | 45 | 52 | 60 | 66 | 72 | 78 | 88 | 94 |
| 40 | 15 | 20 | 27 | 34 | 41 | 48 | 55 | 61 | 67 | 73 | 84 | 91 |
| 50 | 14 | 19 | 25 | 31 | 37 | 44 | 50 | 56 | 62 | 68 | 79 | 88 |
| 60 | 14 | 18 | 23 | 29 | 34 | 40 | 46 | 52 | 58 | 64 | 75 | 84 |
| 80 | 13 | 17 | 21 | 26 | 31 | 36 | 41 | 46 | 52 | 57 | 69 | 78 |
| 100 | 13 | 16 | 20 | 24 | 28 | 32 | 37 | 42 | 47 | 52 | 63 | 73 |

* Power greater than .995.

## TABLE 9.4.1

### L as a Function of Power and u at a = .01

| u | Power .25 | .50 | .60 | 2/3 | .70 | .75 | .80 | .85 | .90 | .95 | .99 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.62 | 6.64 | 8.00 | 9.03 | 9.61 | 10.56 | 11.68 | 13.05 | 14.88 | 17.81 | 24.03 |
| 2 | 4.67 | 8.19 | 9.75 | 10.92 | 11.57 | 12.64 | 13.88 | 15.40 | 17.43 | 20.65 | 27.42 |
| 3 | 5.44 | 9.31 | 11.01 | 12.27 | 12.97 | 14.12 | 15.46 | 17.09 | 19.25 | 22.67 | 29.83 |
| 4 | 6.07 | 10.23 | 12.04 | 13.38 | 14.12 | 15.34 | 16.75 | 18.47 | 20.74 | 24.33 | 31.80 |
| 5 | 6.63 | 11.03 | 12.94 | 14.34 | 15.12 | 16.40 | 17.87 | 19.66 | 22.03 | 25.76 | 33.50 |
| 6 | 7.13 | 11.75 | 13.74 | 15.21 | 16.01 | 17.34 | 18.87 | 20.73 | 23.18 | 27.04 | 35.02 |
| 7 | 7.58 | 12.41 | 14.47 | 15.99 | 16.83 | 18.20 | 19.79 | 21.71 | 24.24 | 28.21 | 36.41 |
| 8 | 8.01 | 13.02 | 15.15 | 16.73 | 17.59 | 19.00 | 20.64 | 22.61 | 25.21 | 29.29 | 37.69 |
| 9 | 8.40 | 13.59 | 15.79 | 17.41 | 18.30 | 19.75 | 21.43 | 23.46 | 26.12 | 30.30 | 38.89 |
| 10 | 8.78 | 14.13 | 16.39 | 18.05 | 18.96 | 20.46 | 22.18 | 24.25 | 26.98 | 31.26 | 40.02 |
| 11 | 9.14 | 14.64 | 16.96 | 18.67 | 19.60 | 21.13 | 22.89 | 25.01 | 27.80 | 32.16 | 41.09 |
| 12 | 9.48 | 15.13 | 17.50 | 19.25 | 20.20 | 21.77 | 23.56 | 25.73 | 28.58 | 33.02 | 42.11 |
| 13 | 9.80 | 15.59 | 18.03 | 19.81 | 20.78 | 22.38 | 24.21 | 26.42 | 29.32 | 33.85 | 43.09 |
| 14 | 10.12 | 16.04 | 18.53 | 20.35 | 21.34 | 22.97 | 24.83 | 27.08 | 30.03 | 34.64 | 44.02 |
| 15 | 10.42 | 16.48 | 19.01 | 20.86 | 21.88 | 23.53 | 25.43 | 27.72 | 30.72 | 35.40 | 44.93 |
| 16 | 10.72 | 16.90 | 19.48 | 21.37 | 22.40 | 24.08 | 26.01 | 28.34 | 31.39 | 36.14 | 45.80 |
| 20 | 11.81 | 18.45 | 21.21 | 23.22 | 24.32 | 26.11 | 28.16 | 30.63 | 33.85 | 38.86 | 49.03 |
| 24 | 12.80 | 19.86 | 22.78 | 24.90 | 26.06 | 27.94 | 30.10 | 32.69 | 36.07 | 41.32 | 51.93 |
| 28 | 13.70 | 21.15 | 24.21 | 26.44 | 27.65 | 29.62 | 31.88 | 34.59 | 38.11 | 43.58 | 54.60 |
| 32 | 14.55 | 22.35 | 25.55 | 27.87 | 29.13 | 31.19 | 33.53 | 36.35 | 40.01 | 45.67 | 57.08 |
| 40 | 16.10 | 24.54 | 27.99 | 30.48 | 31.84 | 34.04 | 36.55 | 39.56 | 43.46 | 49.49 | 61.57 |
| 50 | 17.83 | 27.00 | 30.72 | 33.40 | 34.86 | 37.22 | 39.92 | 43.14 | 47.31 | 53.74 | 66.59 |
| 60 | 19.39 | 29.21 | 33.18 | 36.04 | 37.59 | 40.10 | 42.96 | 46.38 | 50.79 | 57.58 | 71.12 |
| 80 | 22.18 | 33.15 | 37.55 | 40.72 | 42.43 | 45.21 | 48.36 | 52.11 | 56.96 | 64.39 | 79.13 |
| 100 | 24.63 | 36.62 | 41.40 | 44.84 | 46.70 | 49.70 | 53.10 | 57.16 | 62.38 | 70.37 | 86.18 |

## TABLE 9.4.2

### L AS A FUNCTION OF POWER AND u AT a = .05

| | Power | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| u | .25 | .50 | .60 | 2/3 | .70 | .75 | .80 | .85 | .90 | .95 | .99 |
| 1 | 1.65 | 3.84 | 4.90 | 5.71 | 6.17 | 6.94 | 7.85 | 8.98 | 10.51 | 13.00 | 18.37 |
| 2 | 2.26 | 4.96 | 6.21 | 7.17 | 7.70 | 8.59 | 9.64 | 10.92 | 12.65 | 15.44 | 21.40 |
| 3 | 2.71 | 5.76 | 7.15 | 8.21 | 8.79 | 9.76 | 10.90 | 12.30 | 14.17 | 17.17 | 23.52 |
| 4 | 3.08 | 6.42 | 7.92 | 9.05 | 9.68 | 10.72 | 11.94 | 13.42 | 15.40 | 18.57 | 25.24 |
| 5 | 3.41 | 6.99 | 8.59 | 9.79 | 10.45 | 11.55 | 12.83 | 14.39 | 16.47 | 19.78 | 26.73 |
| 6 | 3.70 | 7.50 | 9.19 | 10.44 | 11.14 | 12.29 | 13.62 | 15.26 | 17.42 | 20.86 | 28.05 |
| 7 | 3.97 | 7.97 | 9.73 | 11.04 | 11.77 | 12.96 | 14.35 | 16.04 | 18.28 | 21.84 | 29.25 |
| 8 | 4.22 | 8.40 | 10.24 | 11.60 | 12.35 | 13.59 | 15.02 | 16.77 | 19.08 | 22.74 | 30.36 |
| 9 | 4.45 | 8.81 | 10.71 | 12.12 | 12.89 | 14.17 | 15.65 | 17.45 | 19.83 | 23.59 | 31.39 |
| 10 | 4.67 | 9.19 | 11.15 | 12.60 | 13.40 | 14.72 | 16.24 | 18.09 | 20.53 | 24.38 | 32.36 |
| 11 | 4.88 | 9.56 | 11.58 | 13.07 | 13.89 | 15.24 | 16.80 | 18.70 | 21.20 | 25.14 | 33.29 |
| 12 | 5.08 | 9.90 | 11.98 | 13.51 | 14.35 | 15.74 | 17.34 | 19.28 | 21.83 | 25.86 | 34.16 |
| 13 | 5.28 | 10.24 | 12.36 | 13.93 | 14.80 | 16.21 | 17.85 | 19.83 | 22.44 | 26.54 | 35.00 |
| 14 | 5.46 | 10.55 | 12.73 | 14.34 | 15.22 | 16.67 | 18.34 | 20.36 | 23.02 | 27.20 | 35.81 |
| 15 | 5.64 | 10.86 | 13.09 | 14.73 | 15.63 | 17.11 | 18.81 | 20.87 | 23.58 | 27.84 | 36.58 |
| 16 | 5.81 | 11.16 | 13.43 | 15.11 | 16.03 | 17.53 | 19.27 | 21.37 | 24.12 | 28.45 | 37.33 |
| 20 | 6.46 | 12.26 | 14.71 | 16.51 | 17.50 | 19.11 | 20.96 | 23.20 | 26.13 | 30.72 | 40.10 |
| 24 | 7.04 | 13.26 | 15.87 | 17.78 | 18.82 | 20.53 | 22.49 | 24.85 | 27.94 | 32.76 | 42.59 |
| 28 | 7.57 | 14.17 | 16.93 | 18.94 | 20.04 | 21.83 | 23.89 | 26.36 | 29.60 | 34.64 | 44.86 |
| 32 | 8.07 | 15.02 | 17.91 | 20.02 | 21.17 | 23.04 | 25.19 | 27.77 | 31.14 | 36.37 | 46.98 |
| 40 | 8.98 | 16.58 | 19.71 | 21.99 | 23.23 | 25.25 | 27.56 | 30.33 | 33.94 | 39.54 | 50.83 |
| 50 | 10.00 | 18.31 | 21.72 | 24.19 | 25.53 | 27.71 | 30.20 | 33.19 | 37.07 | 43.07 | 55.12 |
| 60 | 10.92 | 19.88 | 23.53 | 26.17 | 27.61 | 29.94 | 32.59 | 35.77 | 39.89 | 46.25 | 58.98 |
| 80 | 12.56 | 22.67 | 26.75 | 29.70 | 31.29 | 33.88 | 36.83 | 40.34 | 44.89 | 51.89 | 65.83 |
| 100 | 14.00 | 25.12 | 29.59 | 32.80 | 34.54 | 37.36 | 40.56 | 44.37 | 49.29 | 56.85 | 71.84 |

## TABLE 9.4.3

### L AS A FUNCTION OF POWER AND u AT a = .10

| | Power | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| u | .25 | .50 | .60 | 2/3 | .70 | .75 | .80 | .85 | .90 | .95 | .99 |
| 1 | .91 | 2.70 | 3.60 | 4.30 | 4.70 | 5.38 | 6.18 | 7.19 | 8.56 | 10.82 | 15.77 |
| 2 | 1.27 | 3.56 | 4.65 | 5.50 | 5.97 | 6.77 | 7.71 | 8.88 | 10.46 | 13.02 | 18.56 |
| 3 | 1.55 | 4.18 | 5.41 | 6.36 | 6.88 | 7.76 | 8.80 | 10.08 | 11.80 | 14.57 | 20.51 |
| 4 | 1.78 | 4.69 | 6.04 | 7.06 | 7.63 | 8.57 | 9.68 | 11.05 | 12.88 | 15.83 | 22.09 |
| 5 | 1.98 | 5.14 | 6.58 | 7.66 | 8.27 | 9.27 | 10.45 | 11.89 | 13.82 | 16.91 | 23.44 |
| 6 | 2.16 | 5.53 | 7.06 | 8.20 | 8.84 | 9.90 | 11.13 | 12.64 | 14.65 | 17.87 | 24.65 |
| 7 | 2.33 | 5.90 | 7.50 | 8.70 | 9.36 | 10.47 | 11.75 | 13.32 | 15.41 | 18.75 | 25.74 |
| 8 | 2.49 | 6.24 | 7.91 | 9.16 | 9.85 | 10.99 | 12.32 | 13.95 | 16.11 | 19.55 | 26.76 |
| 9 | 2.63 | 6.55 | 8.29 | 9.58 | 10.30 | 11.48 | 12.86 | 14.54 | 16.77 | 20.31 | 27.70 |
| 10 | 2.77 | 6.85 | 8.65 | 9.99 | 10.73 | 11.95 | 13.37 | 15.10 | 17.39 | 21.02 | 28.58 |
| 11 | 2.90 | 7.13 | 8.99 | 10.37 | 11.13 | 12.39 | 13.85 | 15.62 | 17.97 | 21.69 | 29.42 |
| 12 | 3.03 | 7.40 | 9.31 | 10.73 | 11.52 | 12.81 | 14.30 | 16.12 | 18.53 | 22.33 | 30.22 |
| 13 | 3.15 | 7.66 | 9.62 | 11.08 | 11.89 | 13.21 | 14.74 | 16.60 | 19.06 | 22.94 | 30.99 |
| 14 | 3.26 | 7.91 | 9.92 | 11.42 | 12.24 | 13.59 | 15.16 | 17.06 | 19.57 | 23.53 | 31.72 |
| 15 | 3.37 | 8.15 | 10.21 | 11.74 | 12.58 | 13.96 | 15.56 | 17.50 | 20.06 | 24.09 | 32.42 |
| 16 | 3.48 | 8.38 | 10.49 | 12.05 | 12.91 | 14.32 | 15.95 | 17.93 | 20.54 | 24.64 | 33.10 |
| 20 | 3.88 | 9.24 | 11.53 | 13.21 | 14.14 | 15.65 | 17.40 | 19.51 | 22.30 | 26.66 | 35.62 |
| 24 | 4.25 | 10.02 | 12.46 | 14.25 | 15.24 | 16.85 | 18.70 | 20.94 | 23.88 | 28.48 | 37.88 |
| 28 | 4.58 | 10.73 | 13.32 | 15.21 | 16.25 | 17.95 | 19.90 | 22.25 | 25.33 | 30.14 | 39.95 |
| 32 | 4.89 | 11.39 | 14.11 | 16.10 | 17.19 | 18.97 | 21.01 | 23.46 | 26.68 | 31.69 | 41.87 |
| 40 | 5.46 | 12.60 | 15.57 | 17.73 | 18.90 | 20.83 | 23.03 | 25.69 | 29.13 | 34.50 | 45.37 |
| 50 | 6.10 | 13.95 | 17.19 | 19.54 | 20.82 | 22.91 | 25.29 | 28.15 | 31.87 | 37.64 | 49.27 |
| 60 | 6.68 | 15.18 | 18.66 | 21.18 | 22.55 | 24.78 | 27.33 | 30.38 | 34.34 | 40.47 | 52.78 |
| 80 | 7.71 | 17.34 | 21.26 | 24.09 | 25.62 | 28.11 | 30.95 | 34.34 | 38.72 | 45.49 | 58.99 |
| 100 | 8.61 | 19.26 | 23.55 | 26.65 | 28.32 | 31.04 | 34.13 | 37.51 | 42.58 | 49.93 | 64.45 |

MULTIPLE LINEAR REGRESSION VIEWPOINTS
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# UNMEASURED VARIABLES IN PATH ANALYSIS: ADDENDUM

Lee M. Wolfle

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A minor error in Wolfle (1979) should be noted in order to correct a misunderstanding about the measurement reliabilities of educational attainment in the national longitudinal study (NLS) of the high school class of 1972 (Levinsohn, et al., 1978), and to prevent readers of the original paper from ill-advisedly replicating the error.

Tables 3, 4, and 5 in Wolfle (1979) indicate that reliability coefficients may be estimated by the equation:

$$\lambda_{ij} \, (\sigma^2_{\tau_j} \, / \, \sigma^2_i) \; ,$$

where $\lambda_{ij}$ is a regression coefficient estimated by LISREL (Jöreskog and Sörbom, 1978) of the i-th manifest variable on the j-th latent factor, or true score. In fact, the reliability estimate of $x_i$ is given by:

$$\lambda^2_{ij} \, (\sigma^2_{\tau_j} \, / \, \sigma^2_i) \; ;$$

that is, the square of the standardized coefficient, or correlation, between $x_i$ and its true score. This is not a mere typographical error, because it led the author to incorrectly calculate the estimated reliability coefficients.

For example, Table 3 (Wolfle, 1979) indicates that the reliability of V1627, a composite variable of father's educational attainment, exceeds the reliability of a straightforward single question about father's education. In fact, the reliability of the latter variable (.96) exceeds that of the composite (.88).

Among the manifest indices of educational attainment, Wolfle (1979, p. 40) was led to conclude that a composite variable of educational attainment constructed at the National Center for Education Statistics by Fran Melone did not measure the same latent dimension as measured by NLS variables V1854 (educational attainment as of 10/1/76) and V1855 (educational expectations as of 10/1/76). In fact, the reliability coefficients of these three variables are, respectively, .85, .83, and .73 , indicating that the most reliable indicators of educational attainment among whites are the NCES composite and V1854.

Fortunately, these errors were restricted to the measurement portion of the model, and do not affect any of the coefficients or interpretations of the structural portion of the model.

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1978 Analysis of Linear Structural Relationships by the Method of Maximum Likelihood. Chicago: National Educational Resources, Inc.

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Wolfle, Lee M.

1979 "Unmeasured variables in path analysis." Multiple Linear Regression Viewpoints 9: 20 - 56.

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