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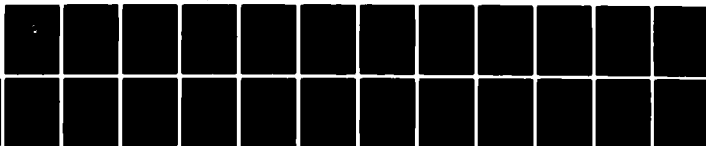
NAVAL POSTGRADUATE SCHOOL MONTEREY CA
TI-59 PROGRAMS FOR MULTIPLE REGRESSION.(U)
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TI-59 PROGRAMS FOR
MULTIPLE REGRESSION

by

D. R. Barr

May 1980

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Prepared for:

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Monterey, California 93940

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TI-59 PROGRAMS FOR MULTIPLE REGRESSION

by

D. R. Barr

1. Introduction

The general linear hypothesis model of full rank [Graybill, 1961] can be written as

$$\begin{matrix} Y & = & X & \beta & + & \epsilon & , & & \epsilon \sim N(0, \sigma^2 I) \\ n \times 1 & & n \times k & k \times 1 & & n \times 1 & & & \end{matrix}$$

where Y is the vector of n dependent variable values to be observed, X is the "design matrix" of fixed values of the independent variables, β is a vector of unknown fixed coefficients in the model and ϵ is the unobservable random error vector. The i^{th} row in this matrix equation,

$$Y_i = x_{0i}\beta_0 + \beta_1 x_{1i} + \dots + \beta_k x_{ki} + \epsilon_i ,$$

represents the i^{th} dependent value to be observed as a linear function of the i^{th} set of independent variable values:

$x_{0i}, x_{1i}, \dots, x_{ki}$.

The solution to the normal equations for estimating β ,

$$(x'x)\hat{\beta} = x'y ,$$

where y is the $n \times 1$ vector of observed outcomes on Y , can be found using program 02 in the TI-59 master module, provided $x'x$ is of full rank k and $1 < k < 9$. Due to space requirements for computing $x'x$, the program presented here requires $k < 8$. Also, because of optional programs (which run faster) for $k = 2$ (OP12-OP15 and $\Sigma+$) and $k = 3$ (statistics module program 18), the programs presented here are most useful for $3 < k < 8$. There is no limit on the number of observations, n . Tests of hypotheses about components of β can be carried out using a "reduced model" solution, and confidence intervals for linear functions of the coefficients can be obtained using $(x'x)^{-1}$ and $\hat{\sigma}^2$, based on the t -distribution, as outlined in [1]. Tests and confidence intervals for σ^2 can be obtained from $\hat{\sigma}^2$, based on the χ^2 distribution.

2. The Programs

Listings of two programs are given in the appendix.

Program #1 serves two purposes:

- (a) computation of $x'x$, $x'y$ and $y'y$ as rows of the data matrix $\begin{pmatrix} x \\ y \end{pmatrix}$ are entered;
- (b) computation of $\hat{\beta}$, $\hat{\beta}'x'y$ and $(x'x)^{-1}$ for the full model.

Program #2 also serves two purposes:

- (a) computation of reduced model components $(x'x)_r$ and $(x'y)_r$, and loading them into memory;
- (b) computation of $\hat{\beta}'_r(x'y)_r$ for the reduced model.

A multiple regression problem is solved with these programs following the sequence:

- (a) load Program #1 (2 banks)
- (b) enter rows of the data matrix
- (c) store $x'x$ and $x'y$ on cards
- (d) compute and record $\hat{\beta}$, $\hat{\beta}'x'y$, $(x'x)^{-1}$, $y'y$ and $x'y$
- (e) load Program #2 (1 bank), along with the stored data
- (f) compute $\hat{\beta}'_r(x'y)_r$ for the reduced model.

Steps (c), (e) and (f) are optional, depending on whether it is desired to test hypotheses that various components of β are zero. Components of $\hat{\beta}$ and $(x'x)^{-1}$ can be recalled from memory (or listed on the printer using the "INV LIST" command) as desired.

Entering each row of the data matrix and updating $x'x$, $x'y$ and $y'y$ requires from 30-60 seconds, depending on k . Computation of $\hat{\beta}$ and $(x'x)^{-1}$ requires from 1 minute to 12 minutes, again depending on the dimension of $x'x$. In what follows, we give instructions for using the programs in the TI program record format. This is followed by an annotated example printer output (use of the printer is optional). Program listings are given in the Appendix.

3. Instructions

Instructions for running the programs are given in Figures 1 and 2. Using the quantities computed when both programs are used, an "analysis of variance" summary can be constructed. The format of this table, and sources of its entries, are given below, in Figure 3. An hypothesis of the form $H_0: \beta_i = 0$ is tested with the F ratio with the " β_i sum of squares" in the numerator and the "error mean square"

$$\hat{\sigma}^2 = \frac{y'y - \hat{\beta}'x'y}{n - k}$$

in the denominator. Degrees of freedom for this F ratio would be 1 and $n-k$. Note that the sum of squares due to regression in the full model, $\hat{\beta}'x'y$, generally is not partitioned into independent components due to $\beta_0, \beta_1, \dots, \beta_k$ unless the design is "orthogonal" ($x'x$ is diagonal). Thus, tests of several hypotheses about components of β are generally not statistically independent. See [Searle, 1972] for a discussion of how to proceed if it is desired to test several hypotheses in the non-orthogonal case.

If one wishes to compute the coefficient of determination R^2 (which is not as useful as the related F-ratio), proceed as follows. First, compute the "adjusted total sum of squares," $SST_{(adj)} = y'y - (\sum y_i)^2/n$, where $y'y$ is stored in register 78, $\sum y_i$ in register 71* and n in register 08 at the first step of Program 1. Then

* See Comment in Figure 3.

TITLE MULTIPLE REGRESSION--PGM #2 PAGE 1 OF 1PROGRAMMER BARR DATE 4/1/80TI Programmable
Program Record Partitioning (Op 17) [3,1,9,7,9] Library Module MASTER Printer OPTIONAL Cards 1
(Bank 1)

PROGRAM DESCRIPTION

For use with multiple regression program #1 to compute the reduced model components $(x'x)_r$ and $(x'y)_r$, and to compute the sum of squares due to regression in the reduced model, $\hat{\beta}'_r(x'y)_r$.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	Enter full data $(x'x, x'y)$ into Banks 2, 3, 4.			
2	Load PGM #2 into Bank 1.			
3	Enter variable to be omitted (Repeat if several variables to be omitted-- omit in decreasing order of subscripts)		A	0
4	Compute $\hat{\beta}'_r(x'y)_r$		B	$\hat{\beta}'_r(x'y)_r$

USER DEFINED KEYS	DATA REGISTERS (INV IN)		LABELS (Op 08) (see listing)
A Omit variables	0 00-79 used	0	(INV) (INV) (CE) (CLR) (x1) (x2)
B Compute $\hat{\beta}'_r(x'y)_r$	1	1	(F) (1/x) (STO) (RCL) (SUM) (y)
C	2	2	(EE) (E) (1) (+) (GT0) (X)
D	3	3	(SCR) (C) (RST) (C) (R/S) (C)
E	4	4	(+/-) (E) (CLR) (INV) (M) (M)
A	5	5	(M) (M) (P-1) (M) (M) (M)
B	6	6	(M) (M) (M) (M) (M) (M)
C	7	7	(M) (M) (M) (M) (M) (M)
D	8	8	(M) (M) (M) (M) (M) (M)
E	9	9	(M) (M) (M) (M) (M) (M)
FLAGS	0	1	2
			5
			6
			7
			8
			9

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FIGURE 2

Index	Source	Degrees of Freedom	Sums of Squares
1.	Regression (full)	k	$\hat{\beta}'x'y$ (Pgm 1)
2 ₀ .	β_0	1	$\hat{\beta}'x'y - \hat{\beta}'_r(x'y)_r$ (Pgms 1 & 2)
2 ₁ .	β_1	1	
$\vdots$	$\vdots$		$\vdots$
3.	Mean	1	$\bar{y}^2$ (from $\sum y_i$ in first component of $x'y$, Pgm 1)*
4.	Error	n-k	$y'y - \beta'x'y$ (Pgm 1)
5.	Total	n	$y'y$

FIGURE 3. AOV Summary

* Provided the first column of X is a vector of 1's.

$$R^2 = \frac{SST_{(adj)} - SSE}{SST_{(adj)}} ,$$

where the sum of squares due to error is given by

$$SSE = y'y - \hat{\beta}'x'y = (n-k)\hat{\sigma}^2 .$$

4. Example. ($k = 3$ example from the TI "Applied Statistics" module booklet; page 5-15)

- (1) Read in Program #1, banks 1 and 2,
- (2) enter "3", press E,
- (3) enter first row of $(x \begin{smallmatrix} \vdots \\ y \end{smallmatrix})$, as follows (do not forget the "1" corresponding to the constant term):

1/ R/S, 0, R/S, 0, R/S, 17.3, R/S, B (next row index displays),

(repeat this sequence, entering 9 rows of data as in Table 5.2, which we produce in Table 1 for convenience.

row number	a_0	a_1	a_2	dependent variable
1	1	0	0	17.3
2	1	0	1	18.1
3	1	0	2	18.7
4	1	1	0	18.6
5	1	1	1	19.1
6	1	1	2	19.5
7	1	2	0	19.6
8	1	2	1	19.9
9	1	2	2	20.3

Table 1

- (4) write banks 2, 3, 4 to save $x'x$, $x'y$ if tests of hypotheses about coefficients are desired (see listings below). Save $y'y$ (register 78) and $\sum y_i$ (register 71),
- (5) press C to compute $\hat{\beta}$, $\hat{\beta}'x'y$, $(x'x)^{-1}$,
- (6) recall and note desired components, as follows (see listing below)
 - a) columns of $(x'x)^{-1}$ in registers 08 to 16, order of columns permuted; permutation stored in 17, 18, 19
 - b) $\hat{\beta}$ in registers 20, 21, 22
 - c) $x'y$ in registers 71, 72, 73
 - d) $y'y$ (total sum of squares) in register 78
 - e) $\beta'x'y$ (sum of squares due to regression) in register 79.
- (7) To test $H_0: a_0 = 0$ (for example) reduce model to eliminate the first independent variable as follows:
 - a) read in data (stored at step 2) in banks 2, 3, 4
 - b) read in Program #2, bank 1
 - c) enter the variable to be deleted ("1" in this case), press A
 - d) when computation is complete, Press B to compute the reduced sum of squares due to regression
 - e) when computation is complete, the sum of squares due to regression in the reduced model $\hat{\beta}'_r(x'y)_r$ (where "r" means "reduced"), is displayed and is stored in register 79.

f) The F-ratio for testing $H_0:a_0 = 0$ is formed as follows:

$$\frac{\hat{\beta}'x'y - \hat{\beta}'_r(x'y)_r}{(y'y - \hat{\beta}'x'y)/(n-k)} = 2705.2$$

degrees of freedom are 1 and $(n-k) = 6$.

- (7') If it is desired to test other hypotheses of the form $H_0:a_i = 0$, repeat the steps in (7) above, with appropriate entry of "i" at step (7c). (Step (7b) need not be repeated.)
- (7") It is desired to test a hypothesis that several coefficients are jointly zero, $H_0:a_i = a_j = \dots = a_m = 0$, repeat step (7c) for each variable to be deleted, in descending order of magnitude of the subscripts. In this case, the F-ratio shown in (7f) should be divided by the number (say s) of remaining variables, and the F statistic has s and $n-k$ degrees of freedom.
- (8) Values obtained for the example and the hypothesis illustrated in step (7) are shown on the attached printouts. A summary AOV table is shown in Table 2.

Source	df	SS	F
Regression: full	3	3259.7161	
<u> reduced</u>	<u>2</u>	<u>2565.8327</u>	$\frac{693.88}{.1539/6} = 27$
due to a_0	1	693.8834	
Total	9	3259.87	
Error	6	$(3259.87 - 3259.7161) = .1539$	$\hat{\sigma}^2 = .1539/6$

Table 2. Summary AOV for example.

EXAMPLE RESULTS

At Step 4

	57.	00
	10.	01
	0.	02
	3.	03
	3.	04
	72.	05
	60.	06
k	3.	07
n	9.	08
	9.	09
	9.	10
	9.	11
x'x	15.	12
	9.	13
	9.	14
	9.	15
	15.	16
	0.	17
	0.	18
	0.	19
	0.	70
Σy_i	171.1	71
x'y	176.8	72
	174.1	73
	0.	74
	0.	75
	0.	76
	0.	77
yy'	3259.87	78
	0.	79

Step 5

$|x'x|$

324.

	9.	00
	16.	01
	16.	02
	19.	03
	3.	04
	4.	05
	324.	06
	3.	07
$x'x^{-1}$	-.1666666667	08
	-7. -13	09
	.1666666667	10
	-.1666666667	11
	.1666666667	12
	0.	13
	.4444444444	14
	-.1666666667	15
	-.1666666667	16
	3.	17
Permutation	2.	18
	1.	19
	17.56111111	20
$\hat{\beta}$	0.95	21
	0.5	22
	0.	23
	0.	24
	0.	25
	0.	70
	171.1	71
	176.8	72
	174.1	73
	0.	74
	0.	75
	0.	76
	0.	77
$y'y$	3259.87	78
$\hat{\beta}'x'y$	3259.716111	79

	9.	00
	16.	01
	0.	02
	0.	03
	73.	04
	74.	05
	1.	06
	2.	07
reduced	15.	08
x'x	9.	09
(omit a_0)	9.	10
	15.	11
	9.	12
	9.	13
	15.	14
	0.	15
	15.	16
	0.	17
	0.	18
	0.	19
	0.	20

Step 7c-7e:

(enter "1",
press "A")

	0.	70
reduced	176.8	71
x'y	174.1	72
	174.1	73
	0.	74
	0.	75
	0.	76
	0.	77
y'y	3259.87	78
	0.	79

(Press "B")

$|x'x_r|$ 144.

$\hat{\beta}'_r(x'y)_r$ 2565.832708

(displayed and stored in 79)

APPENDIX 1

PROGRAM LISTINGS

Note: Program #1 is recorded with standard partitioning; when run it internally partitions the calculator to 319.79. Program #2 and data cards storing x'x and x'y (if written) are written with 319.79 partitioning.

If it is desired to write Program #1 after it has been run, repartition back to standard format prior to writing (enter 6, press "2nd OP 17").

PROGRAM 1

LABEL ADDRESSES

001	15	E
009	18	C'
025	11	A
034	12	B
044	17	B'
104	16	A'
134	13	C
149	33	X ²
157	34	IX
178	35	1/X
217	23	LN X
226	24	CE

MULTIPLE REGRESSION

PROGRAM 1

000	76	LBL	026	72	ST*	052	05	05
001	15	E	027	00	00	053	05	5
002	47	CMS	028	69	DP	054	07	7
003	42	STD	029	20	20	055	85	+
004	07	07	030	91	R/S	056	43	RCL
005	08	8	031	61	GTO	057	04	04
006	69	DP	032	11	A	058	54	)
007	17	17	033	76	LBL	059	42	STD
008	76	LBL	034	12	B	060	06	06
009	18	C'	035	22	INV	061	73	RC*
010	73	RC*	036	86	STF	062	05	05
011	06	06	037	01	01	063	65	X
012	33	X ²	038	00	0	064	73	RC*
013	44	SUM	039	42	STD	065	06	06
014	78	78	040	03	03	066	54	)
015	05	5	041	42	STD	067	32	XIT
016	07	7	042	04	04	068	87	IFF
017	42	STD	043	76	LBL	069	01	01
018	00	00	044	17	B'	070	16	A'
019	69	DP	045	05	5	071	08	8
020	21	21	046	07	7	072	85	+
021	43	RCL	047	85	+	073	43	RCL
022	01	01	048	43	RCL	074	04	04
023	91	R/S	049	03	03	075	85	+
024	76	LBL	050	54	)	076	53	(
025	11	A	051	42	STD	077	43	RCL

078 07 07
 079 65 x
 080 43 RCL
 081 03 03
 082 54)
 083 54)
 084 42 STD
 085 05 05
 086 32 XIT
 087 74 SM*
 088 05 05
 089 69 DP
 090 24 24
 091 43 RCL
 092 07 07
 093 32 XIT
 094 43 RCL
 095 04 04
 096 22 INV
 097 77 GE
 098 17 B'
 099 86 STF
 100 01 01
 101 61 GTD
 102 17 B'
 103 76 LBL
 104 16 A'
 105 07 7
 106 01 1
 107 85 +
 108 43 RCL
 109 03 03
 110 54)
 111 42 STD
 112 05 05
 113 32 XIT
 114 74 SM*
 115 05 05
 116 69 DP
 117 23 23
 118 43 RCL
 119 07 07
 120 32 XIT
 121 43 RCL
 122 03 03
 123 67 EQ
 124 18 C'
 125 00 0
 126 42 STD
 127 04 04

128 22 INV
 129 86 STF
 130 01 01
 131 61 GTD
 132 17 B'
 133 76 LBL
 134 13 C
 135 43 RCL
 136 01 01
 137 75 -
 138 01 1
 139 54)
 140 42 STD
 141 00 00
 142 36 PGM
 143 02 02
 144 13 C
 145 01 1
 146 42 STD
 147 03 03
 148 76 LBL
 149 33 X²
 150 43 RCL
 151 03 03
 152 32 XIT
 153 00 0
 154 42 STD
 155 04 04
 156 76 LBL
 157 34 FX
 158 43 RCL
 159 07 07
 160 33 X²
 161 85 +
 162 08 8
 163 85 +
 164 43 RCL
 165 04 04
 166 54)
 167 42 STD
 168 02 02
 169 73 RC*
 170 02 02
 171 67 EQ
 172 35 1/X
 173 69 DP
 174 24 24
 175 61 GTD
 176 34 FX
 177 76 LBL

178 35 1/X
 179 07 7
 180 00 0
 181 85 +
 182 43 RCL
 183 03 03
 184 54)
 185 42 STD
 186 02 02
 187 08 8
 188 85 +
 189 43 RCL
 190 07 07
 191 85 +
 192 43 RCL
 193 07 07
 194 33 X²
 195 85 +
 196 43 RCL
 197 04 04
 198 54)
 199 42 STD
 200 05 05
 201 73 RC*
 202 02 02
 203 72 ST*
 204 05 05
 205 43 RCL
 206 07 07
 207 32 XIT
 208 43 RCL
 209 03 03
 210 67 EQ
 211 23 LNX
 212 69 DP
 213 23 23
 214 61 GTD
 215 33 X²
 216 76 LBL
 217 23 LNX
 218 25 CLR
 219 36 PGM
 220 02 02
 221 15 E
 222 00 0
 223 42 STD
 224 01 01
 225 76 LBL
 226 24 CE

227 08 8
 228 85 +
 229 43 RCL
 230 07 07
 231 33 X²
 232 85 +
 233 43 RCL
 234 07 07
 235 85 +
 236 43 RCL
 237 01 01
 238 54)
 239 42 STD
 240 02 02
 241 07 7
 242 01 1
 243 85 +
 244 43 RCL
 245 01 01
 246 54)
 247 42 STD
 248 05 05
 249 73 RC*
 250 02 02
 251 65 X
 252 73 RC*
 253 05 05
 254 54)
 255 44 SUM
 256 79 79
 257 69 DP
 258 21 21
 259 43 RCL
 260 07 07
 261 32 XIT
 262 43 RCL
 263 01 01
 264 22 INV
 265 77 GE
 266 24 CE
 267 25 CLR
 268 36 PGM
 269 02 02
 270 17 B'
 271 91 R/S
 272 00 0
 273 00 0
 274 00 0
 275 00 0

PROGRAM 2

LABEL ADDRESSES

032	11	A
072	17	B'
114	12	B
147	18	C'
178	19	D'

MULTIPLE REGRESSION

PROGRAM 2

000	76	LBL	030	92	RTN	060	01	1
001	16	A'	031	76	LBL	061	54	)
002	73	RC*	032	11	A	062	42	STD
003	05	05	033	42	STD	063	04	04
004	72	ST*	034	06	06	064	43	RCL
005	04	04	035	65	*	065	07	07
006	69	DP	036	43	RCL	066	75	-
007	25	25	037	07	07	067	02	2
008	69	DP	038	54	)	068	54	)
009	24	24	039	85	+	069	42	STD
010	97	DSZ	040	08	8	070	02	02
011	03	03	041	54	)	071	76	LBL
012	16	A'	042	42	STD	072	17	B'
013	92	RTN	043	05	05	073	43	RCL
014	76	LBL	044	75	-	074	07	07
015	10	E'	045	43	RCL	075	75	-
016	43	RCL	046	07	07	076	01	1
017	07	07	047	54	)	077	54	)
018	75	-	048	42	STD	078	42	STD
019	43	RCL	049	04	04	079	03	03
020	06	06	050	71	SBR	080	71	SBR
021	54	)	051	10	E'	081	16	A'
022	65	*	052	08	8	082	69	DP
023	43	RCL	053	85	+	083	25	25
024	07	07	054	43	RCL	084	69	DP
025	54	)	055	06	06	085	32	32
026	42	STD	056	54	)	086	43	RCL
027	03	03	057	42	STD	087	02	02
028	71	SBR	058	05	05	088	32	XIT
029	16	A'	059	75	-	089	00	0

090	22	INV
091	77	GE
092	17	B'
093	71	SBR
094	10	E'
095	07	7
096	01	1
097	85	+
098	43	RCL
099	06	06
100	54	)
101	42	STD
102	05	05
103	75	-
104	01	1
105	54	)
106	42	STD
107	04	04
108	43	RCL
109	07	07
110	75	-
111	43	RCL
112	06	06
113	54	)
114	42	STD
115	03	03
116	71	SBR
117	16	A'
118	69	DP
119	37	37
120	91	R/S
121	76	LBL
122	12	B
123	00	0
124	42	STD

125	79	79
126	36	PGM
127	02	02
128	13	C
129	43	RCL
130	07	07
131	42	STD
132	00	00
133	43	RCL
134	03	03
135	85	+
136	43	RCL
137	07	07
138	54	)
139	42	STD
140	01	01
141	76	LBL
142	18	C'
143	73	RC*
144	03	03
145	85	+
146	07	7
147	00	0
148	54	)
149	42	STD
150	04	04
151	73	RC*
152	04	04
153	72	ST*
154	01	01
155	69	DP
156	33	33
157	69	DP
158	31	31
159	97	DSZ

160	00	00
161	18	C'
162	69	DP
163	21	21
164	25	CLR
165	36	PGM
166	02	02
167	15	E
168	07	7
169	01	1
170	42	STD
171	02	02
172	76	LBL
173	19	D'
174	73	RC*
175	01	01
176	65	X
177	73	RC*
178	02	02
179	54	)
180	44	SUM
181	79	79
182	69	DP
183	21	21
184	69	DP
185	22	22
186	97	DSZ
187	07	07
188	19	D'
189	43	RCL
190	79	79
191	91	R/S
192	00	0
193	00	0
194	00	0
195	00	0

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