The SAS MAKESPL Macro

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Abstract

The %MAKESPL macro is a SAS macro that makes restricted cubic spline variables to be used in procedures. It is incorporated in several of the macros that test for non-linearity, but can also be used on its own to create spline variables for covariates (allowing better control for the covariates usually using up fewer degrees of freedom).

Keywords: SAS, macro, restricted cubic splines, nonlinear relation

Contents

1: Description

%MAKESPL is a SAS macro that makes restricted cubic spline variables for a given number of knot points or a list of knots. This macro is useful when you wish to control for confounding by a continuous variable with a possibly non-linear relationship with the outcome.

2: Invocation and Details

To call %MAKESPL, your program must know where to look for it. The most efficient way is to include the following statement (or its equivalent) at the top of your program.

```
    options mautosource sasautos='/usr/local/channing/sasautos';
```

%MAKESPL has very few parameters.

```
DATA     The name of data set on which the regression is to be run
         REQUIRED

SPLVBL   The name of the variable to be "splined"
         REQUIRED

NK       The number of knots, if you want %MAKESPL to place them
         automatically. The numbers of knots for which automatic
         knot placement can be done are
         3, 4, 5, 6, 7, 8, 9, 10, 17, 21, 25, and 50.
         See COMPUTATIONAL METHODS for details about knot placement.
         default is 4

KNOT1    The list of knots if you want to determine them.
         If you give a value for KNOT1, this takes precedence over
         any value NK may have.

REFVAL   A value of SPLVBL to use as the reference level for procedures
         that need reference levels (LOGISTIC, log-binomial regression,
         PHREG).
         The macro prints the values of all the spline variables
         when SPLVBL = REFVAL.
         To do this, it adds one observation to the dataset.

         default is the minimum value of SPLVBL

         NOTE:  Sometimes the best way to control for covariates that are
         originally continuous is to use 3 or 4-knot splines,
         rather than sets of indicators for categorical levels
         of the covariates.
         For many purposes (such as plotting and estimation),
         you will need to know the values of the spline variables
         at a specified value for the covariate.  You can find
         this out by using that specified value as REFVAL.

         If you wish to make spline variables for several covariates,
         you must do them one at a time, using the OUTDAT of
         one run as the DATA of the next (See Example 1).
         If you set REFVAL=(value SPLVBL will have in ADJDAT),
         the macro will print out the values.

         NOTE:  If the value of REFVAL is outside the range of your data,
         the macro will give you the following warning message
         in the .log file.
         WARNING:  Your REFVAL, <value of REFVAL> , is
           lower than all values of the exposure in of the data.
           The macro will continue, but the graph may look strange.
           OR
         WARNING:  Your REFVAL, <value of REFVAL> , is
```

```
          higher than all values of the exposure in of the data.
          The macro will continue, but the graph may look strange.

        'The graph may look strange' means that the point for
        which SPLVBL = REFVAL will be included in the plotting points.
        For example, if the range of SPLVBL in the data is 16-40,
        and REFVAL=0, and the predicted value for SPLVBL=0 is a lot
        higher than that for SPLVBL=16, your graph will have a large
        drop from 0 to 16, and all the real information may be squeezed
        into a small part of the graph.

OUTDAT  The name of the dataset %MAKESPL will make.
        This dataset includes all the variables in the original
        dataset, plus the newly made spline variables.
        It has the extra observation made for  SPLVBL = REFVAL.
        If MAKEPTS = T, it includes the plotting points (See below).
        default=_splstuf

MAKEPTS Whether you want to make 501 plotting points for a graph.
        If MAKEPTS = T, the plotting points in the OUTDAT dataset have
        non-missing values for SPLVBL and COVAR (See below).
        Values the outcome variable in your analysis are missing.
        Because the outcome variable is missing, the plotting points
        will not be used in the estimation routine, but those procedures
        that predict values of the outcome based on the model will
        produce predicted values for the graph.
        The macro makes a variable ({\tt _ine_}) in OUTDAT to distinguish
        the plotting points.
        default is F

COVAR   The list of covariates in the model other than SPLVBL.
        This is only required if MAKEPTS=T and there are covariates
        in your model and the vertical axis of your graph will be an
        absolute quantity (predicted probability, value of a continuous
        variable), rather than a relative quantity (relative risk, odds
        ratio).

ADJDAT  The name of a data set with one (1) observation containing
        the values of each covariate to be used for plotting,
        IF there are covariates in your model and MAKEPTS=T.
        This is REQUIRED for PROC MIXED and PROC GENMOD based
        procedures, as well as for the PLOTPROB=T option in
        LGTPHCURV8.
```

3: Examples

Using a data set from HPFS, we are planning to examine the relationship of a number of risk factors to BMI, cross-sectionally in 1986. We plan to use splines for all the continuous variables.

```
   BMI86 is the individual's BMI in 1986
```

```
   age86 is the individual's age (in years) in 1986
   tfat86n is the individual's daily intake of total fat
           in grams per day in 1986
   alco86n is the individual's daily intake of alcohol
           in grams per day in 1986
   smk86 is the individual's smoking status in 1986
           (0=non-smoker, 1=smoker)
```

Example 1. Making splines for age86 and tfat86n.

To make "spline" variables for `age86` and `tfat86n`, and to print out 3 observations from the output data set each time we ran the macro, we used the following code.

```
title2 'make 4 knot splines for age86';
%makespl(data=alld, splvbl=age86, nk=4, refval=55, outdat=a1);

title2 'first 3 observations of a1';
proc print data=a1 (obs=3);
  var age86 age861 age862 tfat86n alco86n bmi86;

title2 'make 5 knot splines for tfat86n';
%makespl(data=a1, splvbl=tfat86n, nk=5, refval=70, outdat=a2);

title2 'first 3 observations of a2';
proc print data=a2 (obs=3);
  var age86 age861 age862 tfat86n tfat86n1 tfat86n2 tfat86n3
  alco86n bmi86;
run;
```

By using the output data set (OUTDAT) from the first run of %MAKESPL as the input data set (DATA) for the second run of %MAKESPL, the output data set of the second run (`a2`) has the spline variables for age86 and for tfat86n.

Since we are not planning to do the analysis before running we left `MAKEPTS=F` (the default) both times.

Since NK for `age86` was 4, the "spline" variables for `age86` are named `age861` and `age862`. Since NK for `tfat86n` was 5, the "spline" variables for `tfat86n` are named `tfat86n1`, `tfat86n2`, and `tfat86n3`. In general the names will be `variable name`1 ...`variable name`(nk-2), where NK is the number of knots, either given to the macro or counted from a list given in KNOT1.

The results of the above bit of program are shown below.
First the macro lists the knot locations.
Because we gave the value 55 for REFVAL in the first call to %MAKESPL and 70 for REFVAL in the second call to %MAKESPL, we get printouts of the values of the "spline" variables at the reference values. If we had not given a value for REFVAL, the macro would have used the

default value (the minimum value of `age86`), and all spline variables would have had value 0 (because the first knot is greater than the minimum).
We will use these in the ADJDAT86 data set (see Example 2).

```
[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        4
make 4 knot splines for age86      15:17 Wednesday, July 24, 2002
Knots for age86
         40 46 54 67

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        5
make 4 knot splines for age86      15:17 Wednesday, July 24, 2002


values of spline variables when age86 is 55

  OBS    AGE86     AGE861     AGE862

11766      55     4.62678    0.99778

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        6
first 3 observations of a1   15:17 Wednesday, July 24, 2002

  OBS   AGE86    AGE861    AGE862   TFAT86N   ALCO86N   BMI86

    1     69    23.8519    9.2181     41.2       0.0     25.1
    2     73    30.0741   11.9835     34.1      39.7     24.3
    3     72    28.5185   11.2922     79.2       0.0     26.3

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        7
make 5 knot splines for tfat86n    15:17 Wednesday, July 24, 2002
Knots for tfat86n
         35.7 53.8 67.5 82.7 110.6

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        8
make 5 knot splines for tfat86n    15:17 Wednesday, July 24, 2002


values of spline variables when tfat86n is 70

  OBS    TFAT86N    TFAT86N1    TFAT86N2    TFAT86N3

11767       70       7.19314     0.75785    .0027852
```

```
[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
```

```
/udd/stleh/helpme/pkb/splex.sas                                  9
first 3 observations of a2   15:17 Wednesday, July 24, 2002

                                    T       T       T
                              T     F       F       F       A
              A       A       F     A       A       A       L
          A   G       G       A     T       T       T       C   B
          G   E       E       T     8       8       8       O   M
     O    E   8       8       8     6       6       6       8   I
     B    8   6       6       6     N       N       N       6   8
     S    6   1       2       N     1       2       3       N   6

    1 69 23.8519  9.2181 41.2  0.0297 0.00000 0.00000  0.0 25.1
    2 73 30.0741 11.9835 34.1  0.0000 0.00000 0.00000 39.7 24.3
    3 72 28.5185 11.2922 79.2 14.6725 2.92104 0.28549  0.0 26.3

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
```

Example 2. Making the data set with plotting points for ALCO86N

We begin where Example 1 left off.

```
/* make data set with one observation to give values of covariates
for plotting points.
We got these values from the MAKESPL above,
because we gave values for REFVAL  */

data adjdat86;
age86=55;  age861=4.626778;  age862=.9978;  tfat86n=70;
tfat86n1=7.19314;  tfat86n2=.75785;  tfat86n3=.002852;  smk86=0;
run;

title2 'make 3 knot splines for ALCO86N.  make plotting points';
%makespl(data=a2, splvbl=alco86n, nk=3, makepts=T, refval=0,
covar=age86 age861 age862
tfat86n tfat86n1 tfat86n2 tfat86n3 smk86,
adjdat=adjdat86, outdat=a3);

title2 'first 3 observations in a3 ';
proc print data=a3 (obs=3);
var age86 age861 age862 tfat86n tfat86n1 tfat86n2 tfat86n3
alco86n alco86n1 bmi86 smk86;
```

```
run;

title2 'first 5 plotting points';
data pltpts;  set a3;  where _ine_ eq 1;
proc print data=pltpts (obs=5);
var age86 age861 age862 tfat86n tfat86n1 tfat86n2 tfat86n3
alco86n alco86n1 bmi86 smk86;
run;
```

The variable `_ine_` is an indicator for being a plotting point (for the latest run of %MAKESPL). The results of this bit of code are below.

```
[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        10
first 3 observations of a3   15:17 Wednesday, July 24, 2002
Knots for alco86n
         0 6 35.1

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        11
first 3 observations of a3   15:17 Wednesday, July 24, 2002


values of spline variables when alco86n is 0

  OBS    ALCO86N    ALCO86N1

11768       0           0
12269       0           0

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        12
first 3 observations of a3
                                  15:17 Wednesday, July 24, 2002

  OBS   AGE86    AGE861    AGE862   TFAT86N   TFAT86N1   TFAT86N2

    1     69    23.8519    9.2181     41.2      0.0297    0.00000
    2     73    30.0741   11.9835     34.1      0.0000    0.00000
    3     72    28.5185   11.2922     79.2     14.6725    2.92104

  OBS   TFAT86N3    ALCO86N    ALCO86N1    BMI86    SMK86

    1    0.00000       0.0       0.0000     25.1      0
    2    0.00000      39.7      13.3333     24.3      0
    3    0.28549       0.0       0.0000     26.3      0

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                        13
```

```
first 5 plotting points            15:17 Wednesday, July 24, 2002

OBS   AGE86    AGE861   AGE862   TFAT86N   TFAT86N1   TFAT86N2

  1     55    4.62678   0.9978      70      7.19314    0.75785
  2     55    4.62678   0.9978      70      7.19314    0.75785
  3     55    4.62678   0.9978      70      7.19314    0.75785
  4     55    4.62678   0.9978      70      7.19314    0.75785
  5     55    4.62678   0.9978      70      7.19314    0.75785

OBS   TFAT86N3    ALCO86N     ALCO86N1     BMI86    SMK86

  1    .002852      0.00     .000000000      .        0
  2    .002852      0.09     .000000592      .        0
  3    .002852      0.18     .000004734      .        0
  4    .002852      0.27     .000015976      .        0
  5    .002852      0.36     .000037870      .        0

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
```

Note that in the plotting points, `bmi86`, which is neither SPLVBL nor in the COVAR list, is missing. Also, values for the `age86`, `tfat86n`, and `smk86` variables are all the same (= the plotting levels from ADJDAT86).

Example 3. Specifying the knots for ALCO86N in advance

Below we show the code and the results from specifying the knots for ALCO86N at 0, 2, and 35, instead of the automatic locations of 0, 6, and 35.1.

```
title2 'make spline variables for ALC86 (=ALCO86N) with knots given';

%makespl(data=a3, splvbl=alc86, knot1=0 2 35, makepts=T,
covar=age86 age861 age862 tfat86n tfat86n1 tfat86n2 tfat86n2 smk86,
adjdat=adjdat86, refval=0, outdat=a4);

title2 'first 6 observations of a4';
proc print data=a4 (obs=6);
var age86 age861 age862 tfat86n tfat86n1 tfat86n2 tfat86n3
alco86n alco86n1 alc86 alc861 bmi86 smk86;
run;


[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                  14
make spline variables for ALC86 (=ALCO86N) with knots given
                                   15:17 Wednesday, July 24, 2002
Knots for alc86
         0 2 35

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
```

```
/udd/stleh/helpme/pkb/splex.sas                                    15
make spline variables for ALC86 (=ALCO86N) with knots given
                                    15:17 Wednesday, July 24, 2002

values of spline variables when alc86 is 0

  OBS    ALC86    ALC861

12270      0         0
12771      0         0

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                    16
first 6 observations of a4
                                    15:17 Wednesday, July 24, 2002

  OBS age86  age861  age862 TFAT86N TFAT86N1 TFAT86N2 TFAT86N3

    1   69  23.8519  9.2181   41.2    0.0297   0.0000  0.00000
    2   73  30.0741 11.9835   34.1    0.0000   0.0000  0.00000
    3   72  28.5185 11.2922   79.2   14.6725   2.9210  0.28549
    4   67  20.7407  7.8354   69.9    7.1304   0.7439  0.00246
    5   69  23.8519  9.2181   83.3   19.2245   4.5761  0.70303
    6   66  19.1867  7.1449   96.6   38.9762  13.0009  3.65301

  OBS ALCO86N   ALCO86N1   ALC86    ALC861   BMI86   SMK86

    1    0.0      0.0000     0.0   0.00000    25.1     0
    2   39.7     13.3333    39.7   4.69143    24.3     0
    3    0.0      0.0000     0.0   0.00000    26.3     0
    4   16.6      2.5468    16.6   1.03963    22.6     0
    5   11.2      1.0027    11.2   0.47269    28.4     .
    6    2.7      0.0160     2.7   0.01577    21.9     0


[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
```

In this example, we printed out the values of the "spline" variables we got from the previous run (with automatic knot placement), as well as the values of the "spline" variables we got from this call to %MAKESPL. Because the knots are in different locations, the values of the "spline" variables are different unless the value of ALCO86N=ALC86 is 0.

Example 4. Automatic knot placement does not yield distinct knots

Since alcohol consumption is skewed toward 0, requiring a large number of knots will lead to at least two of the knots having value 0. This causes an ERROR message.

```
title2 'try to make 8-knot splines for ALCO86N';
%makespl(data=a4, splvbl=alc86, nk=8, makepts=T, refval=0,
covar=age86 age861 age862 tfat86n tfat86n1 tfat86n2 tfat86n2 smk86,
adjdat=adjdat86, outdat=a5);
```

```
[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
/udd/stleh/helpme/pkb/splex.sas                                      17
try to make 8-knot splines for ALCO86N
                                    15:17 Wednesday, July 24, 2002
Knots for alc86
         0 0 1.9 4.6 8.7 14 23.4 69.8
         "

[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[

/udd/stleh/helpme/pkb/splex.sas                                      18
try to make 8-knot splines for ALCO86N
                                    15:17 Wednesday, July 24, 2002
ERROR in macro run:  The spline-making procedure did not generate
   8  distinct knot points.
You will either have to change the number of knot points
     or supply values for the knots, i.e. KNOT1=
The macro will terminate.
[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
```

NOTE: In the women's cohorts, it may be impossible to use automatic placement for 4 knot splines for alcohol intake variables.

4: Computational Methods

1. Automatic Knot Placement

```
  nk   percentile locations of the knots
  --   --------------------------------

   3   5 50 95
   4   5 35 65 95
   5   5 27.5 50 72.5 95
   6   5 23 41 59 77 95
   7   2.5 18.3 34.2 50 65.8 81.7 97.5
   8   1 15 29 43 57 71 85 99
   9   2 14 26 38 50 62 74 86 98
  10   2 12.7 23.3 34 44.7 55.3 68 76.7 87.3 98
  17   2 8 14 20 26 32 38 44 50 56 62 68 74 80 86 92 98
  21   1 4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99
  25   2 6 10 14 18 22 26 30 34 38 42 46 50 54 58 62 66
       70 74 78 82 86 90 94 98
  50   1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35
       37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67
       69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99
```

2 Computation of the spline variables:

Let t_j be the jth knot point.

Let $kd = (t_{nk} - t_1)^{2/3}$, where `kd` is a normalizing parameter to get the spline variables back into the original units.

For a level of the exposure x, xj, the value of the jth spline variable (j runs from 1 to NK-2) is given by

$$x_j = max((x - t_j)/kd, 0)^3$$

$$+ \left(t_{nk-1} - t_j\right) * max((x - t_{nk})/kd, 0)^3$$

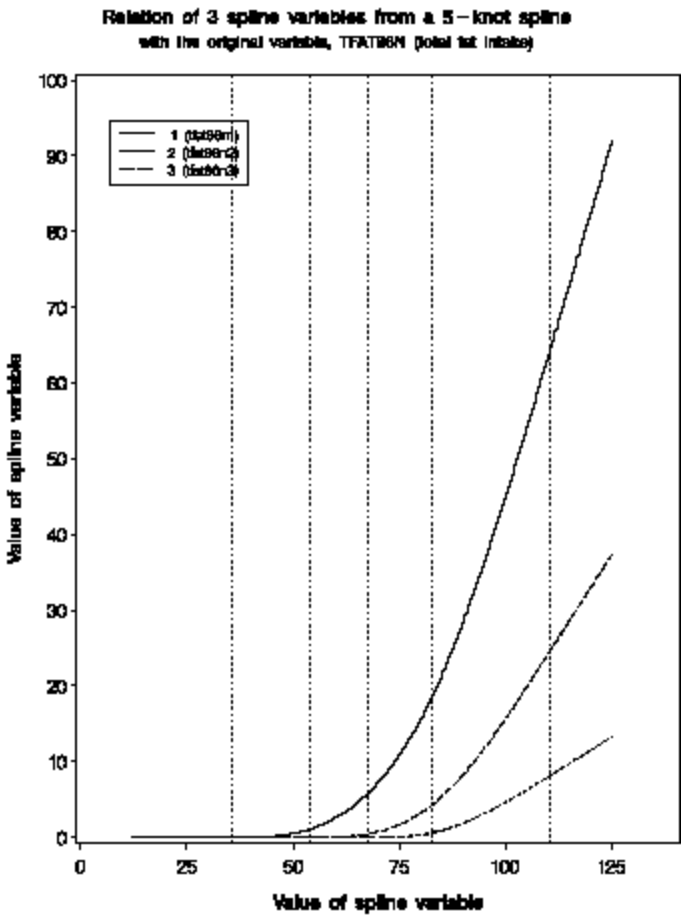
$$- \left(t_{nk} - t_j\right) * max((x - t_{nk-1})/kd, 0)^3)/(t_{nk} - t_{nk-1})$$

For $x<t_j$ the value of the jth spline variable is 0 (as are the 'higher' spline variables) (because all the 'max' values are 0, since $x < t_j < t_{nk-1} < t_{nk}$. As x gets larger, it has more and more nonzero spline variables.

As an example, we show the values of the 3 "spline" variables for the 5 knot splines of tfat86n. The graph below was made using the 'plotting points' using the following code.

```
%makespl( data=alld, splvbl=tfat86n, nk=5, makepts=T, outdat=a99);
data inest;  set a99;
if _ine_ eq 1;
run;
```

This code uses the automatic _ine_ variable to select the 'plotting points.'



The reference lines are at the knot locations.
In fact, `tfat86n1` becomes nonzero at the first knot, `tfat86n2` becomes nonzero at the second knot, and `tfat86n3` becomes nonzero at the third knot. Because of the large range of the vertical axis, this is not visible on the graph.

5: References

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6: Credits

Written by Ellen Hertzmark and Donna Spiegelman for the Channing Laboratory. Based on a macro by Frank Harrell. Questions can be directed to Ellen Hertzmark, stleh@channing.harvard.edu, (617) 432-4957.

7: See Also

Channing SAS macro %LGTPHCURV9