G*Power 3 is a wonderful free resource for power analysis. This program provides power analyses for tests that use F, t, chi-square, or z distributions plus various 'exact' distributions for nonparametric applications.

Power analysis involves four interdependent concepts with the mnemonic BEAN:

> B = beta error, where power = (1 − Beta error)
> E = effect size, in regression measured as $f^2 = R^2$ change / $(1 − \text{cumulative } R^2)$
> A = alpha error rate
> N = sample size

G*Power can compute any one of these four values given the other three. It also offers the option whereby you can specify a 'compromise' B/A ratio, sample size, and effect size, and the program will compute the power and implied alpha error rate.

Download the free program:

G*Power 3, provided by Faul and colleagues, can be freely downloaded from
http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/download-and-register

Options:

The program is loaded with options for power analyses with F, t, z, chi-square, and exact distributions. Within each there are choices for the statistical test. For example, within F are tests for ANOVA, MANOVA, Hotelling's T, and Multiple Regression.

Example of power analysis for multiple regression with G*Power:

Suppose we plan a hierarchical regression analysis with three control variables followed by two treatment variables. We wish to have a 90% chance of attaining statistical significance with alpha = .05 if the population value of R^2 change is large enough to add .10 beyond an anticipated R^2 of .30 produced by the first three control variables. We compute this population effect size to be $f^2 = (R^2 \text{ change}) / (1 − \text{cumulative } R^2) = .1 / (1- (.3+.1)) = .1/.6 = .166667$. This is close to the value of .15 that Cohen (1988) called a 'medium' effect size.

Open G*Power.
Under Test family, select **F tests**.
Under Statistical test, select **Linear Multiple Regression: Fixed model, R^2 increase**.
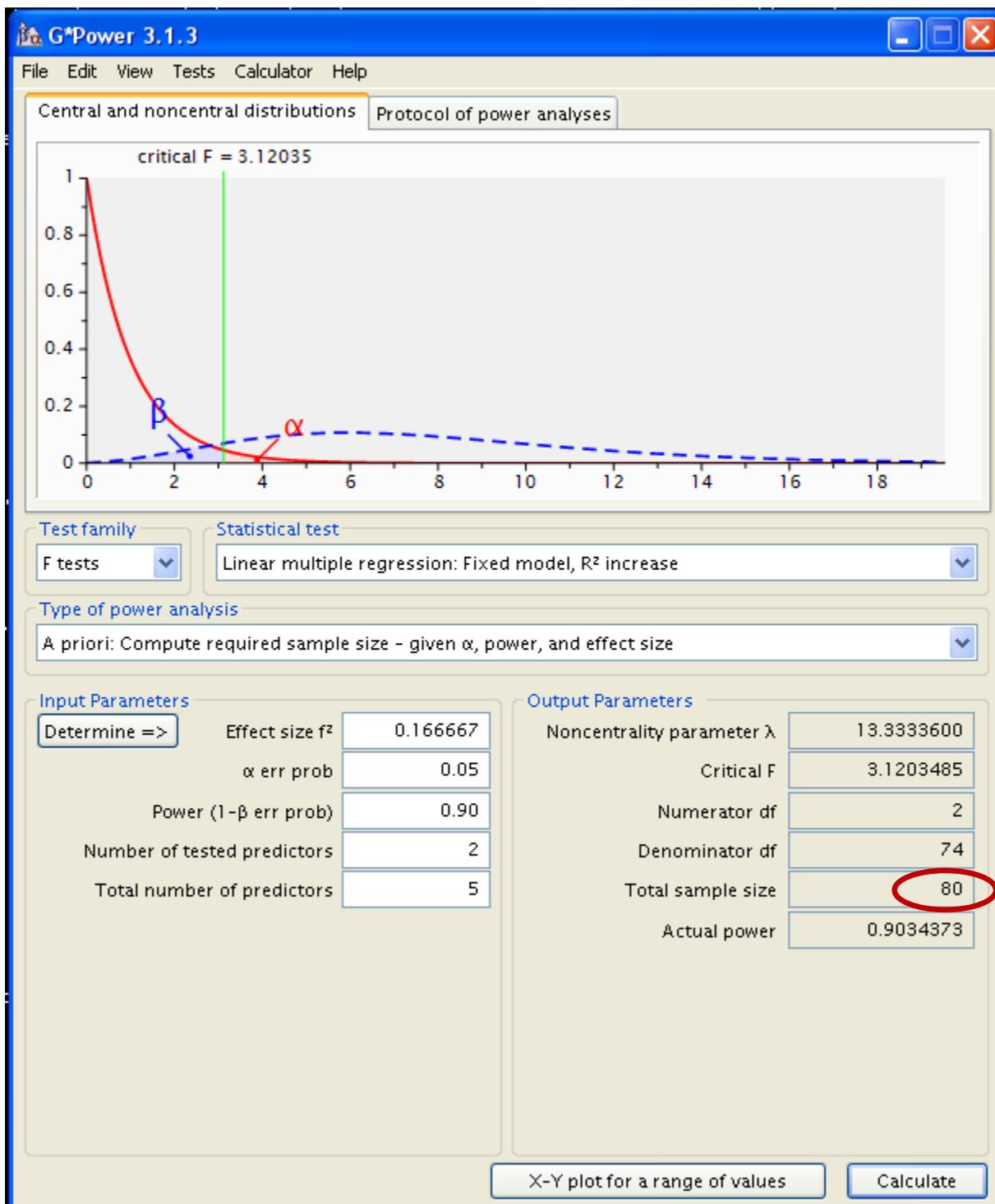Under Type of power analysis, select **A priori: Compute required sample size**
Under Input Parameters, enter the chosen values:
        $f^2 = .166667$; α = .05; Power = .90; Numerator df = 2; Number of predictors = 5

Click **Calculate**. (See graph on the next page.)

The program gives the Total sample size = 80. Power will be greater than 90% if the population effect size is larger than .166667.

This page shows a graphical representation of the null distribution that F is sampled from if the null hypothesis is true (solid curve on left) and the alternate distribution that F is sampled from if the effect size is .166667 and N=80 with alpha = .05 (low dashed-line distribution). If you are not sure how to compute the effect size, the program can help determine that value. The output includes the noncentrality parameter (a measure of effect size), critical F, df for the error term (df=74), Total sample size (N=80), and the actual power (.903).

By pressing **X-Y plot** you can generate a plot showing, for example, sample size on Y as a function of power on X, with separate lines for alternative effect sizes.

Alternate ways to estimate the effect size f ^{2}

Often the most challenging aspect of power analysis is to specify the effect size to be used in the analysis. Logically, this should be the smallest 'meaningful' effect size. If the actual effect size in the population is larger, then power will be larger. If the actual effect size is smaller, power will be less, but presumably the researcher is not greatly interested in having high power to detect such a trivial effect (smaller than 'meaningful'). Based on their knowledge of the variables, different researchers may well disagree on what the smallest meaningful effect is. But the choice should be made using a principled argument, rather than an arbitrary rule, such as a 'medium' effect size based on Cohen's rules of thumb. In some contexts, a 'small' effect may be meaningful, while in other contexts, only a 'large' effect would be meaningful.

When the researcher is interested in the contribution of a specific variable beyond a set of control variables, the effect size can be surprisingly small, especially when the predictor variables are interrelated, as they often are. For example, suppose five potential predictors are all related with pairwise correlations of .30, and each is related to the dependent variable (Y) with a correlation of .25. If you would like to test for the unique contribution of one of the predictors, how large should the sample be to have power of 80% with alpha of .05?

An Excel worksheet in StatWISE can be used to do these computations. StatWISE is under Excel Downloads on http://wise.cgu.edu, and the worksheet is under the **N for MR** tab.

Estimate number of cases needed to test individual multiple regression coefficients

			Table of L values		
				Alpha	
5	Number of predictors		Power	0.05	0.01
0.25	Correlation of every X with Y (rho xy)		0.10	0.43	1.67
0.30	Correlation of every pair of X variables (rho xx)		0.30	2.06	4.21
7.85	L value from table for desired power and alpha error rate		0.50	3.84	6.64
			0.60	4.90	8.00
0.01047	Population R squared added for last predictor		0.70	6.17	9.61
0.142	Population multiple correlation squared		0.75	6.94	10.57
648	N needed for test of individual regression weight		0.80	7.85	11.68
54	N needed for test of overall R squared		0.85	8.98	13.05
			0.90	10.51	14.88
Source	Explanation	Example	Extension	0.95	13.00	17.81
			0.99	18.37	24.03

A sample of N = 648 is needed in this scenario. Why such a large N? Because the effect size is very small. The contribution of the last predictor is only .01047. We can compute f ^{2} as follows:

$$f^2 = (R^2 \text{ change}) / (1 - \text{cumulative } R^2) = .01047 / (1 - .142) = .01047 / .858 = .0122.$$

Using this estimate for f ^{2} in G*Power, with power = .80 and alpha = .05, gives N = 646.

The StatWISE worksheet is based on an excellent paper: Maxwell, S. E. (2000). Sample size and multiple regression analysis. *Psychological Methods, 5*, 434 – 458.

Table 1: Upper 95th Percentage Points of Distribution of Sample Squared Multiple Correlation in Forward Selection

$(n - m - 1)$ **Alpha = .05**

m	k	10	12	14	16	18	20	25	30	35	40	50	60	80	100	150	200
2	1	38	33	29	26	24	22	18	15	13	12	9	8	6	5	3	2
2	2	45	39	35	31	28	26	21	18	16	14	11	10	7	6	4	3
4	1	39	35	31	28	26	24	20	17	15	14	11	9	7	6	4	3
4	2	50	44	40	37	34	31	26	23	20	18	14	12	9	7	5	4
4	3	55	49	45	41	37	34	29	25	22	19	16	13	10	8	5	4
4	4	58	52	47	43	39	36	31	26	23	21	17	14	11	9	6	5
6	1	38	34	31	29	26	25	21	18	16	14	12	10	8	6	4	3
6	2	50	45	41	38	35	33	28	25	22	20	16	14	11	9	6	5
6	3	57	51	47	43	40	38	32	28	25	22	19	16	12	10	7	6
6	4	61	55	51	47	43	40	34	30	27	24	20	17	13	11	7	6
6	6	66	60	55	51	47	44	37	33	29	26	22	18	14	12	8	6
8	1	36	33	30	28	26	24	21	18	16	15	12	11	8	7	5	4
8	2	49	45	41	38	36	34	29	26	23	21	18	15	12	10	7	6
8	3	57	52	48	45	42	39	34	30	27	24	20	18	14	11	8	7
8	4	62	57	52	49	45	43	37	33	29	26	22	19	15	12	9	7
8	6	68	62	57	53	50	47	40	36	32	29	24	21	16	13	10	7
8	8	71	66	61	56	53	49	43	38	34	30	25	22	17	14	10	7
10	1	35	32	29	27	26	24	21	18	16	15	13	11	8	7	5	4
10	2	48	44	41	38	36	34	30	26	24	21	18	16	12	10	7	6
10	3	56	52	48	45	42	40	35	31	28	25	22	19	15	12	9	7
10	4	61	57	53	50	47	44	38	34	31	28	24	21	16	14	10	8
10	6	69	64	59	55	52	49	43	38	34	31	26	23	18	15	11	9
10	8	72	67	63	59	55	52	45	40	36	33	28	24	19	16	11	9
10	10	75	70	65	61	57	54	47	42	38	34	29	25	20	16	11	9
15	1	31	29	27	25	24	23	20	18	16	15	13	11	9	7	5	4
15	2	44	41	39	36	35	33	29	26	24	22	19	16	13	11	8	7
15	3	53	50	47	44	42	40	35	32	29	27	23	20	16	14	10	8
15	4	59	56	53	50	47	45	40	36	33	30	26	23	18	16	11	9
15	6	68	64	60	57	54	52	46	42	38	35	30	26	21	18	13	11
15	8	74	70	66	62	59	56	50	45	41	38	33	29	23	20	14	11
15	10	78	73	69	66	62	59	53	48	43	40	34	30	24	21	15	11
15	15	81	77	73	69	65	62	56	50	46	42	36	31	25	21	15	11
20	1	27	26	24	23	22	21	19	17	16	14	12	11	9	7	5	4
20	2	40	38	36	34	33	31	28	25	23	21	18	16	13	11	8	6
20	3	50	47	45	42	40	38	35	32	29	27	23	21	17	14	10	8
20	4	57	54	51	48	46	44	40	36	33	31	27	24	19	16	12	10
20	6	66	63	60	57	54	52	47	43	39	37	32	28	23	20	14	12
20	8	73	69	66	63	60	57	52	47	44	40	35	31	26	22	16	13
20	10	78	74	70	67	64	61	56	51	47	43	38	33	27	23	17	14
20	15	85	81	77	74	70	67	61	55	51	47	41	37	30	25	18	14
20	20	85	81	77	74	71	68	62	56	52	48	42	37	30	25	18	14

Note: Decimals are omitted; m = number of predictors considered; k = number of predictors selected; n = sample size.

Example: m = 6; k = 3; n = 25; (n − m − 1) = 18. Critical values: $R^2_{.05} = .40$; $R^2_{.01} = .50$
Calculated R^2 must exceed this tabled value to be statistically significant.
Use these tables rather than the test provided by SPSS. Graphical interpolation can be used.

From Wilkinson (1979)

Table 2
Upper 99th Percentage Points of Distribution of Sample Squared Multiple
Correlation in Forward Selection $\alpha = .01$

								$n - m - 1$								
m	k	10	12	14	16	18	20	25	30	35	40	50	60	80	100	150	200
2	1	53	47	42	38	35	32	27	23	20	18	14	12	9	8	5	4
2	2	60	54	48	44	40	37	31	26	23	21	17	14	11	9	6	5
4	1	52	47	42	39	36	33	28	24	22	19	16	14	10	9	6	4
4	2	63	57	51	47	44	41	35	30	27	24	20	17	13	11	7	5
4	3	69	62	56	51	48	44	38	33	29	26	22	19	15	12	8	6
4	4	71	64	59	54	50	47	40	35	31	28	23	20	15	12	8	6
6	1	49	45	41	38	36	33	28	25	22	20	17	14	11	9	6	5
6	2	61	56	52	48	45	42	36	32	29	26	22	19	15	12	8	7
6	3	68	62	57	54	50	47	40	35	32	29	24	21	16	14	9	8
6	4	72	66	61	57	53	49	43	38	34	30	26	22	17	14	10	8
6	6	76	71	66	61	57	54	47	41	37	33	28	24	19	15	10	8
8	1	47	43	40	37	35	32	28	25	22	20	17	14	11	9	6	5
8	2	60	55	51	48	45	42	37	33	29	27	23	20	15	13	9	7
8	3	67	62	58	54	51	48	42	37	33	30	26	22	18	15	10	8
8	4	72	66	62	58	54	51	45	40	36	32	27	24	19	16	11	9
8	6	78	72	67	63	59	55	48	43	39	35	30	26	21	17	12	9
8	8	80	75	70	66	62	59	52	46	41	37	32	27	22	18	12	9
10	1	44	41	38	36	34	32	28	24	22	20	17	15	12	9	7	5
10	2	58	54	50	47	44	42	37	33	30	27	23	20	16	13	9	7
10	3	66	61	57	54	51	48	42	38	34	31	27	23	18	15	11	9
10	4	71	66	62	58	55	52	46	41	37	34	29	25	20	17	12	10
10	6	77	72	67	63	60	57	50	45	40	37	32	28	22	19	14	11
10	8	81	76	71	67	63	60	53	47	43	39	33	29	23	20	14	11
10	10	83	78	74	70	66	63	56	50	45	41	35	30	24	20	14	11
15	1	39	36	34	32	31	29	26	23	21	19	17	15	12	10	7	5
15	2	53	50	47	45	42	40	36	32	29	27	23	20	16	13	9	7
15	3	62	58	55	52	50	47	42	38	35	32	27	24	19	16	11	9
15	4	68	64	60	57	55	52	47	42	38	35	30	27	22	18	13	11
15	6	75	71	67	64	61	58	52	47	43	40	34	30	25	21	15	13
15	8	80	76	72	68	65	62	56	51	46	43	37	33	27	23	17	14
15	10	84	80	76	72	69	66	59	53	49	45	39	35	28	24	18	14
15	15	87	83	80	76	73	70	63	57	53	49	42	37	30	25	18	14
20	1	35	33	31	30	28	27	24	22	20	19	16	14	12	10	7	5
20	2	49	47	44	42	40	38	34	31	28	26	22	20	16	13	9	7
20	3	58	55	52	50	48	46	41	37	34	32	27	24	19	16	11	9
20	4	64	61	58	55	53	51	46	42	38	36	31	27	22	19	13	11
20	6	72	69	66	63	60	58	52	48	44	41	36	32	26	22	16	14
20	8	78	74	71	68	65	63	57	52	48	45	39	35	29	24	18	16
20	10	82	79	75	72	69	66	60	55	51	48	42	37	31	26	20	16
20	15	89	86	82	79	76	73	67	61	57	53	46	41	34	29	21	16
20	20	90	87	83	80	77	75	68	63	58	54	48	42	35	29	21	16

Note: Decimals are omitted; m = number of predictors considered; k = number of predictors selected; n = sample size.

Example: m = 10; k = 4; n = 38; (n − m − 1) = 27.   Critical values: $R^2_{.05} = .36$; $R^2_{.01} = .44$
Calculated R^2 must exceed this tabled value to be statistically significant.
Use these tables rather than the test provided by SPSS. Graphical interpolation can be used.

From Cohen & Cohen (1983)

for one predictor, $K_B = 1$

$$r_{y1}: \quad f^2 = \frac{r^2}{1-r^2}$$

$$L = f^2(n - K_A - K_B - 1)$$

TABLE E.2 — L Values for $\alpha = .05$ ($\alpha = .05$)

k_B					Power						
	.10	.30	.50	.60	.70	.75	.80	.85	.90	.95	.99
1	.43	2.06	3.84	4.90	6.17	6.94	7.85	8.98	10.51	13.00	18.37
2	.62	2.78	4.96	6.21	7.70	8.59	9.64	10.92	12.65	15.44	21.40
3	.78	3.30	5.76	7.15	8.79	9.77	10.90	12.30	14.17	17.17	23.52
4	.91	3.74	6.42	7.92	9.68	10.72	11.94	13.42	15.41	18.57	25.24
5	1.03	4.12	6.99	8.59	10.45	11.55	12.83	14.39	16.47	19.78	26.73
6	1.13	4.46	7.50	9.19	11.14	12.29	13.62	15.26	17.42	20.86	28.05
7	1.23	4.77	7.97	9.73	11.77	12.96	14.35	16.04	18.28	21.84	29.25
8	1.32	5.06	8.41	10.24	12.35	13.59	15.02	16.77	19.08	22.74	30.36
9	1.40	5.33	8.81	10.71	12.89	14.17	15.65	17.45	19.83	23.59	31.39
10	1.49	5.59	9.19	11.15	13.40	14.72	16.24	18.09	20.53	24.39	32.37
11	1.56	5.83	9.56	11.58	13.89	15.24	16.80	18.70	21.20	25.14	33.29
12	1.64	6.06	9.90	11.98	14.35	15.74	17.34	19.28	21.83	25.86	34.16
13	1.71	6.29	10.24	12.36	14.80	16.21	17.85	19.83	22.44	26.55	35.00
14	1.78	6.50	10.55	12.73	15.22	16.67	18.34	20.36	23.02	27.20	35.81
15	1.84	6.71	10.86	13.09	15.63	17.11	18.81	20.87	23.58	27.84	36.58
16	1.90	6.91	11.16	13.43	16.03	17.53	19.27	21.37	24.13	28.45	37.33
18	2.03	7.29	11.73	14.09	16.78	18.34	20.14	22.31	25.16	29.62	38.76
20	2.14	7.65	12.26	14.71	17.50	19.11	20.96	23.20	26.13	30.72	40.10
22	2.25	8.00	12.77	15.30	18.17	19.83	21.74	24.04	27.06	31.77	41.37
24	2.36	8.33	13.02	15.87	18.82	20.53	22.49	24.85	27.94	32.76	42.59
28	2.56	8.94	14.17	16.93	20.04	21.83	23.89	26.36	29.60	34.64	44.87
32	2.74	9.52	15.02	17.91	21.17	23.04	25.19	27.77	31.14	36.37	46.98
36	2.91	10.06	15.82	18.84	22.23	24.18	26.41	29.09	32.58	38.00	48.96
40	3.08	10.57	16.58	19.71	23.23	25.25	27.56	30.33	33.94	39.54	50.83
50	3.46	11.75	18.31	21.72	25.53	27.71	30.20	33.19	37.07	43.07	55.12
60	3.80	12.81	19.88	23.53	27.61	29.94	32.59	35.77	39.89	46.25	58.98
70	4.12	13.79	21.32	25.20	29.52	31.98	34.79	38.14	42.48	49.17	62.53
80	4.41	14.70	22.67	26.75	31.29	33.88	36.83	40.35	44.89	51.89	65.83
90	4.69	15.56	23.93	28.21	32.96	35.67	38.75	42.14	47.16	54.44	68.92
100	4.95	16.37	25.12	29.59	34.54	37.36	40.56	44.37	49.29	56.85	71.84

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To determine n^* to test $R^2_{Y.B}$

$$n^* = \frac{L}{f^2} + K_B + 1$$

$$f^2 = \frac{R^2_{Y.B}}{1 - R^2_{Y.B}}$$

TABLE E.1 — L Values for $\alpha = .01$ ($\alpha = .01$)

k_B					Power						
	.10	.30	.50	.60	.70	.75	.80	.85	.90	.95	.99
1	1.67	4.21	6.64	8.00	9.61	10.57	11.68	13.05	14.88	17.81	24.03
2	2.30	5.37	8.19	9.75	11.57	12.64	13.88	15.40	17.43	20.65	27.42
3	2.76	6.22	9.31	11.01	12.97	14.12	15.46	17.09	19.25	22.67	29.83
4	3.15	6.92	10.23	12.04	14.12	15.34	16.75	18.47	20.74	24.33	31.80
5	3.49	7.52	11.03	12.94	15.12	16.40	17.87	19.66	22.03	25.76	33.50
6	3.79	8.07	11.75	13.74	16.01	17.34	18.87	20.73	23.18	27.04	35.02
7	4.08	8.57	12.41	14.47	16.83	18.20	19.79	21.71	24.24	28.21	36.41
8	4.34	9.03	13.02	15.15	17.59	19.00	20.64	22.61	25.21	29.29	37.69
9	4.58	9.47	13.59	15.79	18.30	19.75	21.43	23.46	26.12	30.31	38.89
10	4.82	9.88	14.13	16.39	18.97	20.46	22.18	24.25	26.98	31.26	40.02
11	5.04	10.27	14.64	16.96	19.60	21.13	22.89	25.01	27.80	32.16	41.09
12	5.25	10.64	15.13	17.51	20.21	21.77	23.56	25.73	28.58	33.02	42.11
13	5.45	11.00	15.59	18.03	20.78	22.38	24.21	26.42	29.32	33.85	43.09
14	5.65	11.35	16.04	18.53	21.34	22.97	24.83	27.09	30.03	34.64	44.03
15	5.84	11.67	16.48	19.01	21.88	23.53	25.43	27.72	30.72	35.40	44.93
16	6.02	12.00	16.90	19.48	22.40	24.08	26.01	28.34	31.39	36.14	45.80
18	6.37	12.61	17.70	20.37	23.39	25.12	27.12	29.52	32.66	37.54	47.46
20	6.70	13.19	18.45	21.21	24.32	26.11	28.16	30.63	33.85	38.87	49.03
22	7.02	13.74	19.17	22.01	25.21	27.05	29.15	31.69	34.99	40.12	50.51
24	7.32	14.27	19.86	22.78	26.06	27.94	30.10	32.69	36.07	41.32	51.93
28	7.89	15.26	21.15	24.21	27.65	29.62	31.88	34.59	38.11	43.58	54.60
32	8.42	16.19	22.35	25.55	29.13	31.19	33.53	36.35	40.01	45.67	57.07
36	8.92	17.06	23.48	26.80	30.52	32.65	35.09	38.00	41.78	47.63	59.39
40	9.39	17.88	24.54	27.99	31.84	34.04	36.55	39.56	43.46	49.49	61.57
50	10.48	19.77	27.00	30.72	34.86	37.23	39.92	43.14	47.31	53.74	66.59
60	11.46	21.48	29.21	33.18	37.59	40.10	42.96	46.38	50.79	57.58	71.12
70	12.37	23.05	31.25	35.45	40.10	42.75	45.76	49.35	53.99	61.11	75.27
80	13.22	24.51	33.15	37.55	42.43	45.21	48.36	52.11	56.96	64.39	79.13
90	14.01	25.89	34.93	39.53	44.62	47.52	50.80	54.71	59.75	67.47	82.76
100	14.76	27.19	36.62	41.41	46.70	49.70	53.11	57.16	62.38	70.37	86.18

To determine n^* to test $R^2_{Y.AB} - R^2_{Y.A}$

$$n^* = \frac{L}{f^2} + K_A + K_B + 1$$

$$f^2 = \frac{R^2_{Y.AB} - R^2_{Y.A}}{1 - R^2_{Y.AB}}$$

$$\frac{f^2}{\;}$$

.02 = "small"
.15 = "medium"
.35 = "large"

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