

Chapter 8

Multiple Regression Analysis: The Problem of Inference

Hypothesis Testing in Multiple Regression

1. Hypothesis Testing about Individual Regression Coefficients
2. Testing the Overall Significance of the Sample Regression
3. Testing the Equality of Two Regression Coefficients
4. Restricted Least Squares: Testing Linear Equality Restrictions
5. Testing for Structural or Parameter Stability of Regression Models: The Chow Test

Hypothesis Testing about Individual Regression Coefficients

Hypothesis Testing about Individual Regression Coefficients

- State the hypothesis $H_0 : \beta_j = 0$
 $H_1 : \beta_j \neq 0$
- t-value
$$t = \frac{(\hat{\beta}_j - \beta_j)}{se(\hat{\beta}_j)}, df = n - 3$$
- critical value $t > t_{\alpha/2} \text{ or } t < t_{\alpha/2}$
- Conclusion
Reject the null hypothesis if $t > t_{\alpha/2}$
Not Reject the null hypothesis if $t < t_{\alpha/2}$

Example

TABLE 6.4 Fertility and Other Data for 64 Countries

Observation	CM	FLF	PCNP	TFR	Observation	CM	FLF	PCNP	TFR
1	128	37	1870	6.66	33	142	50	8640	7.17
2	204	22	130	6.15	34	104	62	350	6.60
3	202	16	310	7.00	35	287	31	230	7.00
4	197	65	570	6.25	36	41	66	1620	3.91
5	96	76	2050	3.81	37	312	11	190	6.70
6	209	26	200	6.44	38	77	88	2090	4.29
7	170	45	670	6.19	39	142	22	900	3.43
8	240	29	300	5.89	40	262	22	230	6.50
9	241	11	120	5.89	41	215	12	140	6.25
10	55	55	290	2.36	42	246	9	330	7.10
11	75	87	1180	3.93	43	191	31	1010	7.16
12	129	55	900	5.99	44	182	19	300	7.00
13	24	93	1750	3.50	45	37	88	1750	3.46
14	165	31	1150	7.41	46	103	35	780	5.66
15	94	77	1160	4.21	47	67	85	1300	4.82
16	96	80	1270	5.00	48	143	78	930	5.00
17	148	30	580	5.27	49	83	85	890	4.74
18	98	69	660	5.21	50	223	33	200	6.49
19	161	43	420	6.50	51	240	19	450	6.50
20	118	47	1080	6.12	52	312	21	280	6.50
21	269	17	290	6.19	53	12	79	4430	1.69
22	189	35	270	5.05	54	52	83	270	3.25
23	136	58	560	6.16	55	79	43	1340	7.17
24	12	81	4240	1.80	56	61	88	670	3.52
25	167	29	240	4.75	57	168	28	410	6.09
26	135	65	430	4.10	58	28	95	4370	2.86
27	107	87	3020	6.66	59	121	41	1310	4.88
28	72	63	1420	7.28	60	115	62	1430	3.89
29	128	49	420	8.12	61	186	45	300	6.90
30	27	63	19830	3.23	62	67	85	3630	4.10
31	152	84	420	5.79	63	178	45	220	6.09
32	224	23	530	6.50	64	142	67	560	7.20

Note: CM is Child mortality, the number of deaths of children under age 5 in a year per 1000 live births; FLF is female literacy rate, percent; PCNP is population under 15, percent; TFR is total fertility rate, 1981-1985, the average number of children born to a woman, using age-specific fertility rates for a given year.
Source: Charles Waddock, Harold White, and Mark White, *Econometrics and Data Analysis for Developing Countries*, Routledge, London, 1994, p. 494.

Source	SS	df	MS			
Model	257362.373	2	128681.187		Number of obs =	64
Residual	106315.627	61	1742.87913		F(2, 61) =	73.83
					Prob > F =	0.0000
					R-squared =	0.7077
					Adj R-squared =	0.6981
					Root MSE =	41.748
Total	363678	63	5772.66667			

	cm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
pgnp		-.0056466	.0020033	-2.82	0.006	-.0096524 - .0016408
flr		-2.231586	.2099472	-10.63	0.000	-2.651401 -1.81177
_cons		263.6416	11.59318	22.74	0.000	240.4596 286.8236

$$1) H_0 : \beta_2 = 0 \quad H_1 : \beta_2 \neq 0$$

$$2) t = \frac{\hat{\beta}_2 - \beta_2}{se(\hat{\beta}_2)} = \frac{-0.0056}{0.0020} = -2.8187$$

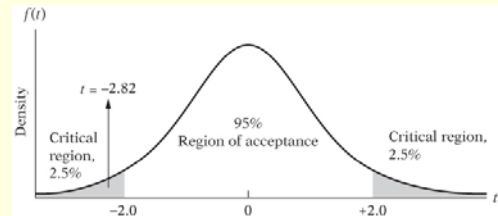
$$3) df = 64 - 3 = 61$$

The critical t value is 2 for a two-tail test ($\alpha = 0.05$)

4) Since the computed t value of 2.8187 exceeds the critical t value of 2

5) We can reject the H_0 that PGNP has no effect on child mortality

The female literacy rate held constant, per capita GNP has a significant negative effect on child mortality



$$H_0 : \beta_2 = 0 \quad H_1 : \beta_2 \neq 0$$

$$\hat{\beta}_2 - t_{\alpha/2} se(\hat{\beta}_2) \leq \beta_2 \leq \hat{\beta}_2 + t_{\alpha/2} se(\hat{\beta}_2)$$

$$-0.0056 - 2(0.0020) \leq \beta_2 \leq -0.0056 + 2(0.0020)$$

$$-0.0096 \leq \beta_2 \leq -0.0016$$

Since the interval does not include the null-hypothesized value of zero, we can reject the null hypothesis. The female literacy rate held constant, per capita GNP has a significant negative effect on child mortality

Analysis of Variance (ANOVA)

- Total Sum of Square (TSS) consists of Explained Sum of Squares (ESS) and Residual Sum of Squares (RSS)

$$\sum y_i^2 = \hat{\beta}_2 \sum y_i x_{2i} + \hat{\beta}_3 \sum y_i x_{3i} + \sum \hat{u}_i^2$$

$$TSS = ESS + RSS$$

$$F = \frac{(\hat{\beta}_2 \sum y_i x_{2i} + \hat{\beta}_3 \sum y_i x_{3i}) / 2}{\sum \hat{u}_i^2 / (n - 3)} = \frac{ESS / df}{RSS / df}$$

F distribution with degree of freedom k-1, n-k

TABLE 8.1
ANOVA Table for the
Three-Variable
Regression

Source of Variation	SS	df	MSS
Due to regression (ESS)	$\hat{\beta}_2 \sum y_i x_{2i} + \hat{\beta}_3 \sum y_i x_{3i}$	2	$\frac{\hat{\beta}_2 \sum y_i x_{2i} + \hat{\beta}_3 \sum y_i x_{3i}}{2}$
Due to residual (RSS)	$\sum \hat{u}_i^2$	$n - 3$	$\hat{\sigma}^2 = \frac{\sum \hat{u}_i^2}{n - 3}$
Total	$\sum y_i^2$	$n - 1$	

Example

TABLE 6.4 Fertility and Other Data for 64 Countries

Observation	CM	FLFP	PCNP	TFR	Observation	CM	FLFP	PCNP	TFR
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6	209	26	200	6.44	38	77	88	2090	4.28
7	170	45	670	5.19	39	142	22	900	5.43
8	240	29	300	5.89	40	262	22	230	6.50
9	241	11	120	5.89	41	215	12	140	6.25
10	55	55	290	2.36	42	246	9	330	7.10
11	75	87	1180	3.93	43	191	31	1010	7.10
12	129	55	900	5.99	44	182	19	300	7.00
13	24	93	1730	3.50	45	37	88	1730	3.46
14	165	31	1150	7.41	46	103	35	780	5.66
15	94	77	1160	4.21	47	67	85	1300	4.82
16	96	80	1270	5.00	48	143	78	930	5.00
17	148	30	580	5.27	49	83	85	690	4.74
18	98	49	660	5.21	50	223	13	200	8.49
19	161	43	420	6.50	51	240	19	450	6.50
20	118	47	1080	6.12	52	312	21	280	6.50
21	269	17	290	6.19	53	12	79	4430	1.69
22	189	35	270	5.05	54	52	83	270	3.23
23	126	58	560	6.16	55	79	43	1340	7.17
24	12	81	4340	1.80	56	41	88	670	3.52
25	167	29	240	4.75	57	168	28	410	6.99
26	133	65	430	4.50	58	28	95	4330	2.86
27	107	87	3020	6.66	59	121	41	1310	4.88
28	72	43	1420	7.28	60	115	42	1470	3.89
29	128	49	420	8.12	61	186	45	300	6.90
30	27	63	19830	5.23	62	47	85	3630	4.10
31	152	84	420	5.79	63	178	45	220	6.09
32	224	23	330	6.50	64	142	67	560	7.20

Note: TFR is Child mortality, the number of deaths of children under age 5 in a year per 1000 live births.
 FLFP = female literacy rate, percent.
 PCNP = per capita GDP in 1985.
 CM = total fertility rate, 1985-1985. The average number of children born to a woman, using age-specific fertility rates for a given year.
 Source: Charles H. Johnson, Ronald White, and Mark White, Economics and Data Analysis for Developing Countries, Routledge, London, 1994, p. 436.

TABLE 8.3
ANOVA Table for the Child Mortality Example

Source of Variation	SS	df	MSS
Due to regression	257,362.4	2	128,681.2
Due to residuals	106,315.6	61	1742.88
Total	363,678	63	

$$F = \frac{128,681.2}{1742.88} = 73.8325$$

The critical F value for 2 df in the numerator and 61 df in the denominator is 3.15 (5% level of significance) or 4.98 (1% level of significance)

Class exercise

จงหาค่า Critical F value

$$F_{0.05}(2, 4)$$

$$F_{0.01}(2, 4)$$

$$F_{0.05}(6, 9)$$

$$F_{0.01}(10, 20)$$

$$F_{0.05}(8, 40)$$

$$F_{0.01}(4, 120)$$

Class exercise

จงหาค่า Critical F value

$$F_{0.05}(2, 4) = 6.94$$

$$F_{0.01}(2, 4) = 18.0$$

$$F_{0.05}(6, 9) = 3.37$$

$$F_{0.01}(10, 20) = 3.37$$

$$F_{0.05}(8, 40) = 2.18$$

$$F_{0.01}(4, 120) = 3.48$$

Testing the Overall Significance of the Sample Regression

Testing the Overall Significance of the Sample Regression-The F Test

Given the k-variable regression model:

$$Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \dots + \beta_k X_{ki} + u_i$$

$$H_0 : \beta_2 = \beta_3 = \dots = \beta_k = 0$$

H_1 : Not all slope coefficients are simultaneously zero

$$F = \frac{ESS / df}{RSS / df} = \frac{ESS / (k - 1)}{RSS / (n - k)}$$

If $F > F_{\alpha}(k - 1, n - k)$, reject H_0

If $F >$ critical region $F_{(1-\alpha);k-1,n-k}$ Reject H_0

If $F <$ critical region $F_{(1-\alpha);k-1,n-k}$ Not reject H_0

R-Squared and F

$$\begin{aligned}
 F &= \frac{ESS/(k-1)}{RSS/(n-k)} \\
 &= \frac{(n-k) ESS}{(k-1) RSS} \\
 &= \frac{(n-k) ESS}{(k-1) TSS - ESS} \\
 &= \frac{(n-k) ESS/TSS}{(k-1) 1 - (ESS/TSS)} \\
 &= \frac{(n-k) R^2}{(k-1) 1 - R^2} \\
 &= \frac{R^2/(k-1)}{(1-R^2)/(n-k)}
 \end{aligned}$$

Testing the Overall Significance of a Multiple Regression in Terms of R-Squared

Given the k-variable regression model:

$$Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \dots + \beta_k X_{ki} + \mu_i$$

$$H_0 : \beta_2 = \beta_3 = \dots = \beta_k = 0$$

H_1 : Not all slope coefficients are simultaneously zero

$$F = \frac{R^2/(k-1)}{(1-R^2)/(n-k)}$$

If $F > F_{\alpha}(k-1, n-k)$, reject H_0

TABLE 8.4
ANOVA Table in
Terms of R^2

Source of Variation	SS	df	MSS*
Due to regression	$R^2(\sum y_i^2)$	2	$R^2(\sum y_i^2)/2$
Due to residuals	$(1-R^2)(\sum y_i^2)$	$n-3$	$(1-R^2)(\sum y_i^2)/(n-3)$
Total	$\sum y_i^2$	$n-1$	

*Note that in computing the F value there is no need to multiply R^2 and $(1-R^2)$ by $\sum y_i^2$ because it drops out, as shown in Eq. (8.4.12).

Example

$$\begin{aligned}
 F &= \frac{R^2/(k-1)}{(1-R^2)/(n-k)} \\
 &= \frac{0.7077/2}{(1-0.7077)/61} = 73.8726
 \end{aligned}$$

The critical F value for 2 df in the numerator and 61 df in the denominator is 3.15 (5 % level of significance) or 4.98 (1% level of significance)

The “incremental” or Marginal contribution of an explanatory variable

In most empirical investigations the researcher may be completely sure whether it is worth adding an X variable to the model knowing that several other X variables are already present in the model

One does not wish to include a variable (s) that contributes very little toward ESS.

One does not want to exclude a variable (s) that substantially increases ESS

How does one decide whether an X variable significantly reduces RSS?

$$\widehat{CM}_i = 157.4244 - 0.114PGNP$$

$$t = (15.9894) \quad (-3.5156)$$

$$p \text{ value} = (0.0000) \quad (0.0008)$$

$$r^2 = 0.1662$$

1. What is the marginal, or incremental, contribution of FLR, knowing that PGNP is already in the model and it is significantly related to CM?
2. Is the incremental contribution of FLR statistically significant?
3. What is the criterion for adding variables to the model?

$$F = \frac{(ESS_{new} - ESS_{old}) / \text{number of new regressors}}{RSS_{new} / df (= n - \text{number of parameters in the new Model})}$$

$$F = \frac{196,912.9}{1742.8786} = 112.9814$$

$$F > \text{critical } F_{\alpha} (\text{number of new regressors}, n - k)$$

F value is highly significant, suggesting that the addition of FLR to the model significantly increases ESS and hence the R-square value

Source	SS	df	MS			
Model	60449.4605	1	60449.4605	Number of obs =	64	
Residual	303228.539	62	4890.78289	F(1, 62) =	12.36	
Total	363678	63	5772.66667	Prob > F =	0.0008	
				R-squared =	0.1662	
				Adj R-squared =	0.1528	
				Root MSE =	69.934	

cm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
pgnp	-.0113645	.0032325	-3.52	0.001	-.0178262	-.0049027
_cons	157.4244	9.845583	15.99	0.000	137.7434	177.1055

Source	SS	df	MS			
Model	257362.373	2	128681.187	Number of obs =	64	
Residual	106315.627	61	1742.87913	F(2, 61) =	73.83	
Total	363678	63	5772.66667	Prob > F =	0.0000	
				R-squared =	0.7077	
				Adj R-squared =	0.6981	
				Root MSE =	41.748	

cm	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
pgnp	-.0056466	.0020033	-2.82	0.006	-.0096524	-.0016408
flr	-2.231586	.2099472	-10.63	0.000	-2.651401	-1.81177
_cons	263.6416	11.59318	22.74	0.000	240.4596	286.8236

$$F = \frac{(R^2_{new} - R^2_{old}) / \text{number of new regressors}}{(1 - R^2_{new}) / df (= n - \text{number of parameters in the new Model})}$$

$$F = \frac{(0.7077 - 0.1662) / 1}{(1 - 0.7077) / 61} = 113.05$$

$$F > \text{critical } F_{\alpha} (k - 1, n - k)$$

Testing the Equality of Two Regression Coefficients

Testing the Equality of Two Regression Coefficients

$$Y_i = \beta_1 + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + u_i$$

$$H_0 : \beta_3 = \beta_4 \text{ or } (\beta_3 - \beta_4) = 0$$

$$H_1 : \beta_3 \neq \beta_4 \text{ or } (\beta_3 - \beta_4) \neq 0$$

$$t = \frac{(\hat{\beta}_3 - \hat{\beta}_4) - (\beta_3 - \beta_4)}{se(\hat{\beta}_3 - \hat{\beta}_4)}$$

Degree of freedom = n-k

$$se(\hat{\beta}_3 - \hat{\beta}_4) = \sqrt{\text{var}(\hat{\beta}_3) + \text{var}(\hat{\beta}_4) - 2\text{cov}(\hat{\beta}_3, \hat{\beta}_4)}$$

$$t = \frac{(\hat{\beta}_3 - \hat{\beta}_4)}{\sqrt{\text{var}(\hat{\beta}_3) + \text{var}(\hat{\beta}_4) - 2\text{cov}(\hat{\beta}_3, \hat{\beta}_4)}}$$

Example

TABLE 7.4
Total Cost (Y) and
Output (X)

Output	Total Cost, \$
1	193
2	226
3	240
4	244
5	257
6	260
7	274
8	297
9	350
10	420

$$\hat{Y}_i = 141.7667 + 63.4777X_i - 12.9615X_i^2 + 0.9396X_i^3$$

$$se = (6.3753) \quad (4.7786) \quad (0.9857) \quad (0.0591)$$

$$COV(\hat{\beta}_3, \hat{\beta}_4) = -0.0576$$

$$R^2 = 0.9983$$

$$H_0 : \beta_3 = \beta_4$$

$$H_1 : \beta_3 \neq \beta_4$$

$$t = \frac{\hat{\beta}_3 - \hat{\beta}_4}{\sqrt{\text{var}(\hat{\beta}_3) + \text{var}(\hat{\beta}_4) - 2\text{cov}(\hat{\beta}_3, \hat{\beta}_4)}} = \frac{-12.9615 - 0.9396}{\sqrt{(0.9867)^2 + (0.0591)^2 - 2(-0.0576)}} = \frac{-13.9011}{1.0442} = -13.3130$$

Degree of freedom = n-k=10-4=6 Check critical value

Reject the null hypothesis

Restricted Least Squares: Testing Linear Equality Restrictions

Example

$$Y_i = \beta_1 X_{2i}^{\beta_2} X_{3i}^{\beta_3} e^{\mu_i}$$

$$\ln Y_i = \beta_0 + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \mu_i$$

โดยที่ $\beta_0 = \ln \beta_1$

Is this restriction valid?

$$\beta_2 + \beta_3 = 1$$

The t-Test Approach

$$t = \frac{(\hat{\beta}_2 + \hat{\beta}_3) - (\beta_2 + \beta_3)}{se(\hat{\beta}_2 + \hat{\beta}_3)}$$

$$= \frac{(\hat{\beta}_2 + \hat{\beta}_3) - (\beta_2 + \beta_3)}{\sqrt{\text{var}(\hat{\beta}_2) + \text{var}(\hat{\beta}_3) + 2\text{cov}(\hat{\beta}_2, \hat{\beta}_3)}}$$

The F-Test Approach: Restricted Least Squares

$\sum \hat{u}_{UR}^2$ RSS of the unrestricted regression

$\sum \hat{u}_R^2$ RSS of the restricted regression

m Number of linear restrictions

k Number of parameters in the unrestricted regression

n Number of observations

$$F = \frac{(RSS_R - RSS_{UR}) / m}{RSS_{UR} / (n - k)}$$

$$= \frac{(\sum \hat{u}_R^2 - \sum \hat{u}_{UR}^2) / m}{\sum \hat{u}_{UR}^2 / (n - k)}$$

$$\sum \hat{u}_{UR}^2 \leq \sum \hat{u}_R^2$$

F distribution with degree of freedom $m, n-k$

$$F = \frac{(R_{UR}^2 - R_R^2) / m}{(1 - R_{UR}^2) / (n - k)}$$

$$R_{UR}^2 \geq R_R^2$$

F distribution with degree of freedom $m, n-k$

Example

Year	GDP*	Employment [†]	Fixed Capital [‡]
1955	114043	8310	182113
1956	120410	8529	193749
1957	129187	8738	205192
1958	134705	8952	215130
1959	139960	9171	225021
1960	150511	9569	237026
1961	157897	9527	248897
1962	165286	9662	260661
1963	178491	10334	275466
1964	199457	10981	295378
1965	212323	11746	315715
1966	226977	11521	337642
1967	241194	11540	363599
1968	260881	12066	391847
1969	277498	12297	422382
1970	296530	12955	455049
1971	306712	13338	484677
1972	329030	13738	520553
1973	354057	15924	561531
1974	374977	14154	609825

*Billions of 1960 pesos.
[†]Thousands of people.
[‡]Millions of 1960 pesos.

$$Y_t = \beta_1 X_{2t}^{\beta_2} X_{3t}^{\beta_3} e^{\mu_t}$$

$$\ln \widehat{GDP}_t = -1.6524 + 0.3397 \ln Labor_t + 0.8460 \ln Capital_t$$

$$t = (-2.7259) \quad (1.8295) \quad (9.0625)$$

$$p \text{ value} = (0.0144) \quad (0.0849) \quad (0.0000)$$

$$R^2 = 0.9951 \quad RSS_{UR} = 0.0136$$

As you can see, the output/labor elasticity is about 0.34 and the output/capital elasticity is about 0.85. If we add these coefficients, we obtain 1.19, suggesting that perhaps the Mexican economy during the stated time period was experiencing increasing returns to scale.

Let us impose the restriction of constant returns to scale

$$\ln(\widehat{GDP} / Labor)_t = -0.4947 + 1.0153 \ln(Capital / Labor)_t$$

$$t = (-4.0612) \quad (28.1056)$$

$$p \text{ value} = (0.0007) \quad (0.0000)$$

$$R_R^2 = 0.9777 \quad RSS_R = 0.0166$$

$$F = \frac{(RSS_R - RSS_{UR}) / m}{RSS_{UR} / (n - k)}$$

$$= \frac{(0.0166 - 0.0136) / 1}{0.0136 / (20 - 3)} = 3.75$$

F-distribution with degree of freedom 1, 17

F-value is not significant at the 5% level

The conclusion is that the Mexican economy was probably characterized by constant returns to scale over the sample period and therefore there may be no harm in using the restricted regression

Testing for Structural or Parameter Stability of Regression Models: The Chow Test

Testing for Structural or Parameter Stability of Regression Models: The Chow Test

- “Structural Change” mean that the values of parameters of the model do not remain the same through the entire period

TABLE 8.9

Savings and Personal Disposable Income (billions of dollars), United States, 1970-1995

Source: Economic Report of the President, 1997, Table B-26, p. 352.

Observation	Savings	Income	Observation	Savings	Income
1970	61.0	727.1	1983	167.0	2522.4
1971	68.6	790.2	1984	235.7	2810.0
1972	63.6	855.3	1985	206.2	3002.0
1973	89.6	965.0	1986	196.5	3187.6
1974	97.6	1054.2	1987	168.4	3363.1
1975	104.4	1159.2	1988	189.1	3640.8
1976	96.4	1273.0	1989	187.8	3894.5
1977	92.5	1401.4	1990	208.7	4166.8
1978	112.6	1580.1	1991	246.4	4343.7
1979	130.1	1769.5	1992	272.6	4613.7
1980	161.8	1973.3	1993	214.4	4790.2
1981	199.1	2200.2	1994	189.4	5021.7
1982	205.5	2347.3	1995	249.3	5320.8

- This table gives data on disposable personal income and personal savings, in billions of dollars, the U.S. for the period 1970-1995
- We want to estimate a simple savings function that relates savings (Y) to disposable personal income (DPI) (X)
- In 1982 the United States suffered its worst peacetime recession –unemployment rate reached 9.7%

- Divide sample data into two time periods:
 - 1970-1981 and 1982-1995
- Three possible regressions:
- Time period 1970-1981: $Y_t = \lambda_1 + \lambda_2 X_t + \mu_{1t}$ $n_1 = 12$
- Time period 1982-1995: $Y_t = \gamma_1 + \gamma_2 X_t + \mu_{2t}$ $n_2 = 14$
- Time period 1970-1995: $Y_t = \alpha_1 + \alpha_2 X_t + \mu_t$ $n = 26$

$$\hat{Y}_t = 1.0161 + 0.0803X_t$$

$$t = (0.0873) \quad (9.6015)$$

$$R^2 = 0.9021 \quad RSS_1 = 1785.032 \quad df = 10$$

$$\hat{Y}_t = 153.4947 + 0.0148X_t$$

$$t = (4.6922) \quad (1.7707)$$

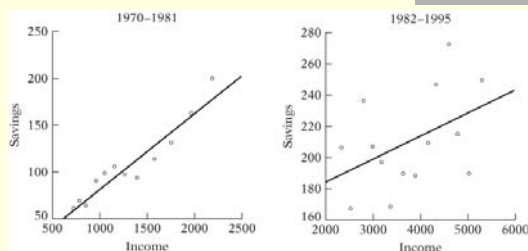
$$R^2 = 0.2971 \quad RSS_2 = 10,005.22 \quad df = 12$$

$$\hat{Y}_t = 62.4226 + 0.0376X_t + \dots$$

$$t = (4.8917) \quad (8.8937) + \dots$$

$$R^2 = 0.7672 \quad RSS_3 = 23,248.30 \quad df = 24$$

- The slope in the preceding savings-income regressions represents the **marginal propensity to save (MPS)**, the mean change in savings as a result of a dollar's increase in disposable personal income



Chow test

Assumption

1. $u_{1t} \sim N(0, \sigma^2)$ and $u_{2t} \sim N(0, \sigma^2)$ - The error terms in the subperiod regressions are normally distributed with the same (homoscedastic) variance
2. The two error terms are independently distributed

The mechanics of the Chow test

1. Estimate $Y_t = \alpha_1 + \alpha_2 X_t + u_t$, $n = 26$, which is appropriate if there is no parameter instability, and obtain RSS_3 with $df = (n_1 + n_2 - k)$. We call RSS_3 the restricted residual sum of squares (RSS_R)
2. Estimate $Y_t = \lambda_1 + \lambda_2 X_t + u_{1t}$, $n_1 = 12$ and obtain its residual sum of squares, RSS_1 , with $df = (n_1 - k)$
3. Estimate $Y_t = \gamma_1 + \gamma_2 X_t + u_{2t}$, $n_2 = 14$ and obtain its residual sum of squares, RSS_2 , with $df = (n_2 - k)$

4. Since the two sets of samples are deemed independent, we can add RSS_1 and RSS_2 to obtain what may be called the **unrestricted residual sum of squares** (RSS_{UR})

$$RSS_{UR} = RSS_1 + RSS_2 \quad \text{with } df = (n_1 + n_2 - 2k)$$

$$RSS_{UR} = (1785.032 + 10,005.22) = 11,790.252$$

5. If there is no structural change, then the RSS_R and RSS_{UR} should not be statistically different.

$$F = \frac{(RSS_R - RSS_{UR}) / k}{(RSS_{UR}) / (n_1 + n_2 - 2k)} \sim F_{[k, (n_1 + n_2 - 2k)]}$$

then the Chow has shown that under the null hypothesis the regression $Y_t = \lambda_1 + \lambda_2 X_t + u_{1t}$, $n_1 = 12$ and $Y_t = \gamma_1 + \gamma_2 X_t + u_{2t}$, $n_2 = 14$ are statistically the same

6. We find that for 2, 22 df the 1 percent critical F value is 5.72.

$$F = \frac{(23,248.30 - 11,790.252) / 2}{(11,790.252) / 22} = 10.69$$

Therefore, the probability of obtaining F value of as much as or greater than 10.69. We reject the null hypothesis of parameter stability and conclude that the regressions $Y_t = \lambda_1 + \lambda_2 X_t + u_{1t}$, $n_1 = 12$ and $Y_t = \gamma_1 + \gamma_2 X_t + u_{2t}$, $n_2 = 14$ are different