

HEWLETT-PACKARD

HP-33E
STATISTICS
Applications



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For Continuous Memory Models

Although this book refers specifically to the HP-33E or HP-38E, the programs and calculations contained herein apply equally well to the HP-33C or HP-38C. The user should note, however, that the display format and data register contents are retained by the calculator even though it has been turned off. It may be desirable to reset or clear these conditions before running programs or making calculations.



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HP-33E

Statistics Applications

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Introduction

This Statistics Applications book was written to help you get the most from your HP-33E calculator. The programs were chosen to provide useful calculations for many of the common problems encountered in statistics.

They will provide you with immediate capabilities in your everyday calculations and you will find them useful as guides to programming techniques for writing your own customized software.

You will find general information on how to key in and run programs under "A Word about Program Usage" in the Applications book you received with your calculator.

We hope that this Statistics Applications book will be a valuable tool in your work and would appreciate your comments about it.

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General Statistics

Covariance and Correlation Coefficient

For a set of given data points $\{(x_i, y_i), i = 1, 2, \dots, n\}$, the covariance and the correlation coefficient are defined as:

$$\text{covariance } s_{xy} = \frac{1}{n(n-1)} (n \sum x_i y_i - \sum x_i \sum y_i)$$

$$\text{or } s_{xy}' = \frac{1}{n^2} (n \sum x_i y_i - \sum x_i \sum y_i)$$

$$\text{correlation coefficient } r = \frac{s_{xy}}{s_x s_y}$$

where s_x and s_y are standard deviations

$$s_x = \sqrt{\frac{n \sum x_i^2 - (\sum x_i)^2}{n(n-1)}}$$

$$s_y = \sqrt{\frac{n \sum y_i^2 - (\sum y_i)^2}{n(n-1)}}$$

Note: $-1 \leq r \leq 1$

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
[f] CLEAR [PRGM]	00	[R/S]	08- 74
[Σ+]	01- 25	[RCL] 2	09- 24 2
[GTO] 00	02- 13 00	1	10- 1
[f] [r]	03- 14 23	[=]	11- 41
[R/S]	04- 74	[x]	12- 61
[g] [s]	05- 15 25	[RCL] 2	13- 24 2
[x]	06- 61	[÷]	14- 71
[x]	07- 61	[GTO] 00	15- 13 00

REGISTERS			
R ₀	R ₁	R ₂ n	R ₃ Σx
R ₄ Σx ²	R ₅ Σy	R ₆ Σy ²	R ₇ Σxy

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		[f] [PRGM] [f] [REG]	
3	Perform this step for			
	$i = 1, 2, \dots, n$	x_i		
		y_i	[R/S]	i
4	Correlation coefficient		[GSB] 03	r
5	Calculate covariance s_{xy}		[R/S]	s_{xy}
6	s_{xy}'		[R/S]	s_{xy}'
7	For a new case go to step 2.			

Example:

x_i	26	30	44	50	62	68	74
y_i	92	85	78	81	54	51	40

Solution:

$$r = -0.9572$$

$$s_{xy} = -354.1429$$

$$s_{xy}' = -303.5510$$

Keystrokes

Display

[f] [PRGM] [f] [REG]	
26 [ENTER] 92 [R/S]	1.0000
30 [ENTER] 85 [R/S]	2.0000
:	
:	
74 [ENTER] 40 [R/S]	7.0000
[GSB] 03	-0.9572
[R/S]	-354.1429
[R/S]	-303.5510

Moments and Skewness

This program calculates the following statistics for a set of given data $\{x_1, x_2, \dots, x_n\}$:

$$1^{\text{st}} \text{ moment } \bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$$

$$2^{\text{nd}} \text{ moment } m_2 = \frac{1}{n} \sum x_i^2 - \bar{x}^2$$

$$3^{\text{rd}} \text{ moment } m_3 = \frac{1}{n} \sum x_i^3 - \frac{3}{n} \bar{x} \sum x_i^2 + 2\bar{x}^3$$

moment coefficient of skewness

$$\gamma_1 = \frac{m_3}{m_2^{3/2}}$$

KEY ENTRY	DISPLAY
1 CLEAR PRGM	00
ENTER	01- 31
9 x²	02- 15 0
Σ+	03- 25
GTO 00	04- 13 00
RCL 5	05- 24 5
RCL 2	06- 24 2
÷	07- 71
STO 6	08- 23 6
R/S	09- 74
RCL 3	10- 24 3
RCL 2	11- 24 2
÷	12- 71
RCL 6	13- 24 6
9 x²	14- 15 0
-	15- 41
STO 1	16- 23 1
R/S	17- 74
RCL 7	18- 24 7
RCL 2	19- 24 2
÷	20- 71
RCL 3	21- 24 3
RCL 6	22- 24 6

KEY ENTRY	DISPLAY
x	23- 61
RCL 2	24- 24 2
÷	25- 71
3	26- 3
x	27- 61
-	28- 41
RCL 6	29- 24 6
ENTER	30- 31
9 x²	31- 15 0
x	32- 61
2	33- 2
x	34- 61
+	35- 51
STO 0	36- 23 0
R/S	37- 74
RCL 0	38- 24 0
RCL 1	39- 24 1
1	40- 1
.	41- 73
5	42- 5
f y²	43- 14 3
÷	44- 71
GTO 00	45- 13 00

REGISTERS			
R ₀ m ₃	R ₁ m ₂	R ₂ n	R ₃ Σx
R ₄ Σx ⁴	R ₅ Σx ²	R ₆ $\bar{x}$	R ₇ Σx ³

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f PRGM f REG	
3	Perform for $i = 1, 2, \dots, n$:			
	Input x-value	x_i	R/S	i
4	Delete erroneous data	x_k	ENTER 9 x² f	
			Σ^-	
5	Calculate the mean		GSB 05	$\bar{x}$
6	Calculate the second and			
	third moments		R/S	m_2
			R/S	m_3
7	Calculate the moment			
	coefficient of skewness		R/S	γ_1
8	For new case, go to step 2.			

Example:

i	1	2	3	4	5	6	7	8	9
x_i	2.1	3.5	4.2	6.5	4.1	3.6	5.3	3.7	4.9

Solution:

$$\bar{x} = 4.21$$

$$m_2 = 1.39$$

$$m_3 = 0.39$$

$$\gamma_1 = 0.24$$

Keystrokes

f **PRGM** **f** **REG**
 2.1 **R/S** 3.5 **R/S**
 4.2 **R/S** ...
 4.9 **R/S**
GSB 05
R/S
R/S
R/S

Display

9.0000
4.2111
1.3899
0.3864
0.2358

Partial Correlation Coefficients

The partial correlation coefficient measures the relationship between any two of the variables when all other are kept constant.

For the case of 3 variables, the partial correlation coefficient between X_1 and X_2 keeping X_3 constant is

$$r_{12 \cdot 3} = \frac{r_{12} - r_{13} r_{23}}{\sqrt{(1 - r_{13}^2)(1 - r_{23}^2)}}$$

where r_{ij} denotes the correlation coefficient of X_i and X_j .

Similarly, for the case of 4 variables, the partial correlation coefficient between X_1 and X_2 keeping X_3 and X_4 constant is

$$r_{12 \cdot 34} = \frac{r_{12 \cdot 4} - r_{13 \cdot 4} r_{23 \cdot 4}}{\sqrt{(1 - r_{13 \cdot 4}^2)(1 - r_{23 \cdot 4}^2)}} = \frac{r_{12 \cdot 3} - r_{14 \cdot 3} r_{24 \cdot 3}}{\sqrt{(1 - r_{14 \cdot 3}^2)(1 - r_{24 \cdot 3}^2)}}$$

Any partial correlation coefficient can be calculated by means of these formulas (using this program) if correlation coefficients r_{12} , r_{13} , r_{23} , ... are given.

Note:

This program finds $r_{13 \cdot 2}$, $r_{23 \cdot 1}$ by similar formulas.

Reference:

S. Wilks. *Mathematical Statistics*, John Wiley and Sons, 1962.

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
[F] CLEAR [PRGM]	00	[STO] 0	13-- 23 0
[STO] 2	01-- 23 2	[RCL] 1	14-- 24 1
[g] x^2	02-- 15 0	[RCL] 2	15-- 24 2
1	03-- 1	[x]	16-- 61
[=]	04-- 41	[=]	17-- 41
[x₂y]	05-- 21	[x₂y]	18-- 21
[STO] 1	06-- 23 1	[÷]	19-- 71
[g] x^2	07-- 15 0	[R/S]	20-- 74
1	08-- 1	[RCL] 1	21-- 24 1
[=]	09-- 41	[RCL] 2	22-- 24 2
[x]	10-- 61	[RCL] 0	23-- 24 0
[f] $\sqrt{x}$	11-- 14 0	[GTO] 01	24-- 13 01
[x₂y]	12-- 21		

REGISTERS

R_0 r_{12}, r_{13}, r_{23}	R_1 r_{13}, r_{23}, r_{12}	R_2 r_{23}, r_{12}, r_{13}	R_3
R_4	R_5	R_6	R_7

Example:

Suppose $r_{12} = -0.96$, $r_{13} = -0.1$, $r_{23} = 0.12$, then the partial correlation coefficients are:

$$r_{12 \cdot 3} = -.96$$

$$r_{13 \cdot 2} = .05$$

$$r_{23 \cdot 1} = .09$$

Keystrokes

Display

.96 **[CHS]** **[ENTER]** .1

[CHS] **[ENTER]** .12

[GSB] 01

[R/S]

[R/S]

-0.9597

0.0547

0.0861

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Input data and calculate correlation coefficients	r_{12}	[ENTER]	
		r_{13}	[ENTER]	
		r_{23}	[GSB] 01	$r_{12 \cdot 3}$
			[R/S]	$r_{13 \cdot 2}$
			[R/S]	$r_{23 \cdot 1}$
3	For a new case, go to step 2.			

Probability

Factorial

This program calculates factorials for positive integers between 2 and 69.

$$n! = n(n-1)(n-2) \dots (2)(1)$$

Notes:

- For large values of n , the program will take some time to arrive at a result, up to a maximum of about 20 seconds for $n = 69$.
- The program checks for the input values automatically. "Error 0" will be displayed for $n < 2$ or $n > 69$, and non-integer numbers.

KEY ENTRY	DISPLAY
f CLEAR PRGM	00
GSB 13	01- 12 13
ENTER *	02- 31
1	03- 1
STO 0	04- 23 0
x²y	05- 21
STO x 0	06- 23 61 0
1	07- 1
=	08- 41
f x²y	09- 14 61
GTO 06	10- 13 06
RCL 0	11- 24 0
GTO 00	12- 13 00
6	13- 6
9	14- 9

KEY ENTRY	DISPLAY
x²y	15- 21
f x²y	16- 14 51
GTO 28	17- 13 28
2	18- 2
f x²y	19- 14 51
GTO 28	20- 13 28
x²y	21- 21
ENTER *	22- 31
g FRAC	23- 15 33
g x²0	24- 15 61
GTO 28	25- 13 28
x²y	26- 21
g RTN	27- 15 12
0	28- 0
+	29- 71

REGISTERS

R ₀ Used	R ₁	R ₂	R ₃
R ₄	R ₅	R ₆	R ₇

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Key in n ($2 \leq n \leq 69$)	n	GSB 01	$n!$
3	For a new n , go to step 2.			

Examples:

- $5! = 120$
- $10! = 3628800$

Keystrokes

5 **GSB** 01
10 **GSB** 01

Display

120.0000
3,628,800.000

Permutation

A permutation is an ordered subset of a set of distinct objects. The number of possible permutations, each containing n objects, that can be formed from a collection of m distinct objects is given by

$${}_m P_n = \frac{m!}{(m-n)!} = m(m-1) \dots (m-n+1)$$

where m, n are integers and $0 \leq n \leq m$.

Notes:

- ${}_m P_n$ can also be denoted by P_n^m , $P(m,n)$ or $(m)_n$.
- ${}_m P_0 = 1$, ${}_m P_1 = m$, ${}_m P_m = m!$

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
f CLEAR PRGM	00	-	23- 41
STO 1	01- 23 1	f X=Y	24- 14 71
x>y	02- 21	GTO 28	25- 13 28
STO 0	03- 23 0	R+	26- 22
RCL 0	04- 24 0	GTO 17	27- 13 17
RCL 1	05- 24 1	R+	28- 22
g X=0	06- 15 71	R+	29- 22
GTO 31	07- 13 31	GTO 00	30- 13 00
f X=Y	08- 14 71	1	31- 1
GTO 33	09- 13 33	GTO 00	32- 13 00
f X>Y	10- 14 51	1	33- 1
GTO 41	11- 13 41	-	34- 41
1	12- 1	g X=0	35- 15 71
f X=Y	13- 14 71	GTO 39	36- 13 39
GTO 43	14- 13 43	STO x 0	37- 23 61 0
R+	15- 22	GTO 33	38- 13 33
-	16- 41	RCL 0	39- 24 0
1	17- 1	GTO 00	40- 13 00
+	18- 51	0	41- 0
x	19- 61	-	42- 71
f LST x	20- 14 73	R+	43- 22
RCL 0	21- 24 0	R+	44- 22
1	22- 1	GTO 00	45- 13 00

REGISTERS			
R ₀ m	R ₁ n	R ₂	R ₃
R ₄	R ₅	R ₆	R ₇

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Input m, n and	m	ENTER	
	calculate permutations	n	GSB 01	${}_m P_n$
3	For a new case, go to step 2.			

Examples:

- ${}_{43}P_3 = 74046$
- ${}_{73}P_4 = 26122320$

Keystrokes**Display**

f **FIX** 0
 43 **ENTER** 3 **GSB** 01 74,046.
 73 **ENTER** 4
GSB 01 26,122,320.

Combination

A combination is a selection of one or more of a set of distinct objects without regard to order. The number of possible combinations, each containing n objects, that can be formed from a collection of m distinct objects is given by

$${}_m C_n = \frac{m!}{(m-n)! n!} = \frac{m(m-1) \dots (m-n+1)}{1 \cdot 2 \cdot \dots \cdot n}$$

where m, n are integers and $0 \leq n \leq m$.

This program calculates ${}_m C_n$ using the following algorithm:

- If $n \leq m - n$

$${}_m C_n = \frac{m-n+1}{1} \cdot \frac{m-n+2}{2} \cdot \dots \cdot \frac{m}{n}$$

- If $n > m - n$, program calculates ${}_m C_{m-n}$.

Notes:

1. ${}_m C_n$, which is also called the binomial coefficient, can be denoted by C_n^m , $C(m,n)$, or $\binom{m}{n}$.
2. ${}_m C_n = {}_m C_{m-n}$
3. ${}_m C_0 = {}_m C_m = 1$
4. ${}_m C_1 = {}_m C_{m-1} = m$

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
$\boxed{\text{f}} \boxed{\text{CLEAR}} \boxed{\text{PRGM}}$	00	$\boxed{\text{x}\div\text{y}}$	17- 21
$\boxed{=}$	01- 41	$\boxed{\text{f}} \boxed{\text{x}>\text{y}}$	18- 14 51
$\boxed{\text{f}} \boxed{\text{LST X}}$	02- 14 73	$\boxed{\text{GTO}} \boxed{24}$	19- 13 24
$\boxed{\text{f}} \boxed{\text{x}\leq\text{y}}$	03- 14 41	$\boxed{\text{f}} \boxed{\text{x}=\text{y}}$	20- 14 71
$\boxed{\text{x}\div\text{y}}$	04- 21	$\boxed{\text{GTO}} \boxed{24}$	21- 13 24
$\boxed{\text{STO}} \boxed{0}$	05- 23 0	$\boxed{\text{RCL}} \boxed{2}$	22- 24 2
1	06- 1	$\boxed{\text{GTO}} \boxed{00}$	23- 13 00
$\boxed{\text{STO}} \boxed{1}$	07- 23 1	$\boxed{\text{x}\div\text{y}}$	24- 21
$\boxed{+}$	08- 51	$\boxed{\text{RCL}} \boxed{0}$	25- 24 0
$\boxed{\text{STO}} \boxed{2}$	09- 23 2	$\boxed{+}$	26- 51
$\boxed{\text{R}\star}$	10- 22	$\boxed{\text{RCL}} \boxed{1}$	27- 24 1
$\boxed{\text{g}} \boxed{\text{x}=0}$	11- 15 71	$\boxed{\div}$	28- 71
$\boxed{\text{GTO}} \boxed{32}$	12- 13 32	$\boxed{\text{STO}} \boxed{\text{x}} \boxed{2}$	29- 23 61 2
1	13- 1	$\boxed{\text{R}\star}$	30- 22
$\boxed{\text{RCL}} \boxed{1}$	14- 24 1	$\boxed{\text{GTO}} \boxed{13}$	31- 13 13
$\boxed{+}$	15- 51	1	32- 1
$\boxed{\text{STO}} \boxed{1}$	16- 23 1	$\boxed{\text{GTO}} \boxed{00}$	33- 13 00

REGISTERS			
R_0 max	R_1 Used	R_2 Used	R_3
R_4	R_5	R_6	R_7

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Key in m, n and calculate combination	m n	$\boxed{\text{ENTER}\star}$ $\boxed{\text{GSB}} \boxed{01}$	${}_m C_n$
3	For a new case, go to step 2.			

Examples:

1. ${}_{73} C_4 = 1088430$
2. ${}_{43} C_3 = 12341$

Keystrokes

Display

$\boxed{\text{f}} \boxed{\text{FIX}} \boxed{0}$
 73 $\boxed{\text{ENTER}\star} \boxed{4} \boxed{\text{GSB}} \boxed{01}$ 1,088,430.
 43 $\boxed{\text{ENTER}\star} \boxed{3} \boxed{\text{GSB}} \boxed{01}$ 12,341.

Random Number Generator

This program calculates uniformly distributed pseudo random numbers u_i in the range

$$0 \leq u_i \leq 1$$

using the following formula:

$$u_i = \text{Fractional part of } [(\pi + u_{i-1})^3].$$

The user has to specify the starting value u_0 (the "seed" of the sequence) such that

$$0 \leq u_0 \leq 1.$$

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
$\boxed{f}$ CLEAR $\boxed{PRGM}$	00	$\boxed{f}$ $\boxed{y^x}$	05- 14 3
$\boxed{9}$ $\boxed{\pi}$	01- 15 73	$\boxed{9}$ $\boxed{FRAC}$	06- 15 33
$\boxed{RCL}$ 0	02- 24 0	$\boxed{STO}$ 0	07- 23 0
$\boxed{+}$	03- 51	$\boxed{GTO}$ 00	08- 13 00
3	04- 3		

REGISTERS			
R_0 u_i	R_2	R_3	R_4
R_5	R_6	R_7	

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Store seed	u_0	$\boxed{STO}$ 0 $\boxed{f}$ $\boxed{PRGM}$	
3	Generate random number		$\boxed{R/S}$	u_i
4	Repeat step 3 as many times as desired			
5	For new sequence, go to step 2.			

Example:

Find the sequence of two digit random numbers generated from a seed of 0.192743568.

Solution:

0.07, 0.14, 0.34, 0.37, 0.17, 0.46, 0.82, ...

Keystrokes**Display**

$\boxed{f}$ $\boxed{PRGM}$ $\boxed{f}$ $\boxed{FIX}$ 2
.192743568 $\boxed{STO}$ 0

$\boxed{R/S}$ 0.07
 $\boxed{R/S}$ 0.14
 $\boxed{R/S}$ 0.34
 $\boxed{R/S}$ 0.37

etc.

Distributions

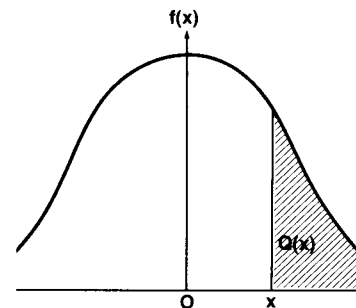
Normal Distribution

The density function for a standard normal variable is

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}$$

The upper tail area is

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt.$$



For $x \geq 0$, polynomial approximation is used to calculate $Q(x)$:

$$Q(x) = f(x) (b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5) + \epsilon(x)$$

where: $|\epsilon(x)| < 7.5 \times 10^{-8}$

$$t = \frac{1}{1 + rx}, \quad r = 0.2316419$$

$$b_1 = .31938153, \quad b_2 = -.356563782$$

$$b_3 = 1.781477937, \quad b_4 = -1.821255978$$

$$b_5 = 1.330274429$$

Note:

The program only works for $x \geq 0$. Equations $f(-x) = f(x)$, $Q(-x) = 1 - Q(x)$, where $x \geq 0$, can be used to find f and Q for negative numbers.

Reference:

Abramowitz and Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, 1968.

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
f CLEAR PRGM	00	ENTER *	21- 31
ENTER *	01- 31	ENTER *	22- 31
STO 6	02- 23 6	ENTER *	23- 31
x	03- 61	RCL 5	24- 24 5
2	04- 2	x	25- 61
÷	05- 71	RCL 4	26- 24 4
CHS	06- 32	+	27- 51
g e^x	07- 15 1	x	28- 61
g π	08- 15 73	RCL 3	29- 24 3
2	09- 2	+	30- 51
x	10- 61	x	31- 61
f √x	11- 14 0	RCL 2	32- 24 2
+	12- 71	+	33- 51
STO 7	13- 23 7	x	34- 61
R/S	14- 74	RCL 1	35- 24 1
RCL 0	15- 24 0	+	36- 51
RCL 6	16- 24 6	x	37- 61
x	17- 61	RCL 7	38- 24 7
1	18- 1	x	39- 61
+	19- 51	GTO 00	40- 13 00
g 1/x	20- 15 3		

REGISTERS			
R ₀ r	R ₁ b ₁	R ₂ b ₂	R ₃ b ₃
R ₄ b ₄	R ₅ b ₅	R ₆ x	R ₇ f(x)

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Store constants	r	STO 0	
		b ₁	STO 1	
		b ₂	STO 2	
		b ₃	STO 3	
		b ₄	STO 4	
		b ₅	STO 5	
3	Input x and calculate f(x)		GSB 01	f(x)
4	Calculate Q(x)		R/S	Q(x)
5	For a new case, go to step 3.			

Examples:

1. $x = 1.18$

2. $x = 2.28$

Solutions:

1. $f(x) = 0.1989$

$Q(x) = 0.1190$

2. $f(x) = 0.0297$

$Q(x) = 0.0113$

Keystrokes

Display

0.2316419 **STO** 0

0.31938153 **STO** 1

0.356563782 **CHS**

STO 2

1.781477937 **STO** 3

1.821255978 **CHS**

STO 4

1.330274429 **STO** 5

1.18 **GSB** 01

R/S

2.28 **GSB** 01

R/S

0.1989

0.1190

0.0297

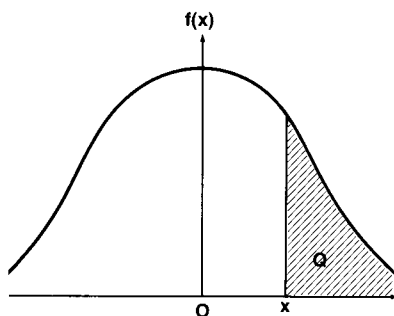
0.0113

Inverse Normal Integral

This program determines the value of x such that

$$Q = \int_x^{\infty} \frac{e^{-\frac{t^2}{2}}}{\sqrt{2\pi}} dt$$

where Q is given and $0 < Q \leq 0.5$.



The following rational approximation is used:

$$x = t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} + \epsilon(Q)$$

where: $|\epsilon(Q)| < 4.5 \times 10^{-4}$

$$t = \sqrt{\ln \frac{1}{Q^2}}$$

$$c_0 = 2.515517 \quad d_1 = 1.432788$$

$$c_1 = 0.802853 \quad d_2 = 0.189269$$

$$c_2 = 0.010328 \quad d_3 = 0.001308$$

Reference:

Abramowitz and Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, 1968.

KEY ENTRY	DISPLAY
[F] CLEAR [PRGM]	00
[ENTER+]	01- 31
[x]	02- 61
[9] [1/x]	03- 15 3
[f] [LN]	04- 14 1
[f] [1/x]	05- 14 0
[STO] 6	06- 23 6
[ENTER+]	07- 31
[ENTER+]	08- 31
[ENTER+]	09- 31
[RCL] 5	10- 24 5
[x]	11- 61
[RCL] 4	12- 24 4
[+]	13- 51
[x]	14- 61
[RCL] 3	15- 24 3
[+]	16- 51

KEY ENTRY	DISPLAY
[x]	17- 61
1	18- 1
[+]	19- 51
[STO] 7	20- 23 7
[CLX]	21- 34
[RCL] 2	22- 24 2
[x]	23- 61
[RCL] 1	24- 24 1
[+]	25- 51
[x]	26- 61
[RCL] 0	27- 24 0
[+]	28- 51
[RCL] 7	29- 24 7
[÷]	30- 71
[=]	31- 41
[GTO] 00	32- 13 00

REGISTERS			
R ₀ c ₀	R ₁ c ₁	R ₂ c ₂	R ₃ d ₁
R ₄ d ₂	R ₅ d ₃	R ₆ t	R ₇ 1 + d ₁ t +

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Store constants	c_0	[STO] 0	
		c_1	[STO] 1	
		c_2	[STO] 2	
		d_1	[STO] 3	
		d_2	[STO] 4	
		d_3	[STO] 5	
3	Input Q to calculate x	Q	[GSB] 01	x
4	For a new case, go to step 3.			

Examples:

1. $Q = 0.12$
2. $Q = 0.05$

Solutions:

1. $x = 1.1751$
2. $x = 1.6452$

Keystrokes

2.515517 **[STO]** 0
0.802853 **[STO]** 1
0.010328 **[STO]** 2
1.432788 **[STO]** 3
0.189269 **[STO]** 4
0.001308 **[STO]** 5
0.12 **[GSB]** 01
0.05 **[GSB]** 01

Display

1.1751
1.6452

Curve Fitting

Exponential Curve Fit

This program calculates the least squares fit of n pairs of data points $\{(x_i, y_i), i = 1, 2, \dots, n\}$, where $y_i > 0$, for an exponential function of the form

$$y = ae^{bx} \quad (a > 0).$$

The equation is transformed into

$$\ln y = \ln a + bx.$$

The following statistics are calculated:

1. Coefficients a, b

$$b = \frac{n \sum x_i \ln y_i - (\sum x_i)(\sum \ln y_i)}{n \sum x_i^2 - (\sum x_i)^2}$$

$$a = \exp \left[\frac{\sum \ln y_i}{n} - b \frac{\sum x_i}{n} \right]$$

2. Coefficient of determination

$$r^2 = \frac{[n \sum x_i \ln y_i - \sum x_i \sum \ln y_i]^2}{[n \sum x_i^2 - (\sum x_i)^2] [n \sum (\ln y_i)^2 - (\sum \ln y_i)^2]}$$

3. Estimated value $\hat{y}$ for a given x

$$\hat{y} = a e^{bx}$$

Note:

n is a positive integer and $n \neq 1$.

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
f CLEAR PRGM	00	R/S	07- 74
f LN	01- 14 1	f r	08- 14 23
x²y	02- 21	g x²	09- 15 0
Σ+	03- 25	R/S	10- 74
GTO 00	04- 13 00	f y	11- 14 22
f L.R.	05- 14 24	g e^x	12- 15 1
g e^x	06- 15 1	R/S	13- 74

REGISTERS			
R ₀	R ₁	R ₂ n	R ₃ Σx
R ₄ Σx ²	R ₅ Σ ln y	R ₆ Σ (ln y) ²	R ₇ Σ x ln y

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f REG f PRGM	
3	Perform for i = 1, ..., n:			
	Input x-value and y-value	x _i	ENTER *	
		y _i	R/S	i
4	Calculate constants		GSB 05	a
			x²y	b
5	Calculate coefficient of determination		R/S	r ²
6	To calculate ŷ, input x	x	GSB 11	ŷ
7	Perform step 6 as many times as desired			
8	For new case, go to step 2.			

Example:

x _i	.72	1.31	1.95	2.58	3.14
y _i	2.16	1.61	1.16	.85	0.5

Solution:

$$a = 3.4451, b = -0.5820$$

$$y = 3.45 e^{-0.58x}$$

$$r^2 = 0.9803$$

$$\text{For } x = 1.5, \hat{y} = 1.4389$$

Keystrokes

f **REG** **f** **PRGM**
 .72 **ENTER*** 2.16
R/S 1.0000
 1.31 **ENTER*** 1.61
R/S 2.0000
 1.95 **ENTER*** 1.16
R/S 3.0000
 2.58 **ENTER*** 0.85
R/S 4.0000
 3.14 **ENTER*** 0.5
R/S 5.0000
GSB 05 3.4451
x²y -0.5820
R/S 0.9803
 1.5 **GSB** 11 1.4389

Logarithmic Curve Fit

This program fits a logarithmic curve

$$y = a + b \ln x$$

to a set of data points

$$\{(x_i, y_i), i = 1, 2, \dots, n\}$$

where: $x_i > 0$.

Program calculates:

1. Regression coefficients

$$b = \frac{n \sum y_i \ln x_i - \sum \ln x_i \sum y_i}{n \sum (\ln x_i)^2 - (\sum \ln x_i)^2}$$

$$a = \frac{1}{n} (\sum y_i - b \sum \ln x_i)$$

2. Coefficient of determination

$$r^2 = \frac{[n \sum y_i \ln x_i - \sum \ln x_i \sum y_i]^2}{[n \sum (\ln x_i)^2 - (\sum \ln x_i)^2] [n \sum y_i^2 - (\sum y_i)^2]}$$

3. Estimated value $\hat{y}$ for given x

$$\hat{y} = a + b \ln x$$

Note:

n is a positive integer and $n \neq 1$.

KEY ENTRY	DISPLAY
$\boxed{\text{f}} \boxed{\text{CLEAR}} \boxed{\text{PRGM}}$	00
$\boxed{x} \boxed{y}$	01— 21
$\boxed{\text{f}} \boxed{\text{LN}}$	02— 14 1
$\boxed{\Sigma+}$	03— 25
$\boxed{\text{GTO}} \boxed{00}$	04— 13 00
$\boxed{\text{f}} \boxed{\text{LR}}$	05— 14 24
$\boxed{\text{R/S}}$	06— 74

KEY ENTRY	DISPLAY
$\boxed{\text{f}} \boxed{\text{r}}$	07— 14 23
$\boxed{9} \boxed{x^2}$	08— 15 0
$\boxed{\text{R/S}}$	09— 74
$\boxed{\text{f}} \boxed{\text{LN}}$	10— 14 1
$\boxed{\text{f}} \boxed{\hat{y}}$	11— 14 22
$\boxed{\text{R/S}}$	12— 74

REGISTERS

R_0	R_1	R_2 n	R_3 $\sum \ln x$
R_4 $\sum (\ln x)^2$	R_5 $\sum y$	R_6 $\sum y^2$	R_7 $\sum (\ln x)(y)$

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		$\boxed{\text{f}} \boxed{\text{REG}} \boxed{\text{f}} \boxed{\text{PRGM}}$	
3	Perform for $i = 1, \dots, n$:			
	Input x-value and y-value	x_i	$\boxed{\text{ENTER}}$	
		y_i	$\boxed{\text{R/S}}$	i
4	Calculate constants		$\boxed{\text{GSB}} \boxed{05}$	a
			$\boxed{x} \boxed{y}$	b
5	Calculate coefficient of determination		$\boxed{\text{R/S}}$	r^2
6	To calculate $\hat{y}$, input x	x	$\boxed{\text{GSB}} \boxed{10}$	$\hat{y}$
7	Perform step 6 as many times as desired			
8	For new case, go to step 2.			

Example:

x_i	3	4	6	10	12
y_i	1.5	9.3	23.4	45.8	60.1

Solution:

$$a = -47.0212, b = 41.3945$$

$$y = -47.02 + 41.39 \ln x$$

$$r^2 = 0.9798$$

$$\text{For } x = 8, \hat{y} = 39.0562$$

$$\text{For } x = 14.5, \hat{y} = 63.67$$

Keystrokes**Display**

f REG f PRGM	
3 ENTER 1.5 R/S	1.0000
4 ENTER 9.3 R/S	2.0000
6 ENTER 23.4 R/S	3.0000
10 ENTER 45.8 R/S	4.0000
12 ENTER 60.1 R/S	5.0000
GSB 05	-47.0212
X$\leftrightarrow$Y	41.3945
R/S	0.9798
8 GSB 10	39.0562
14.5 GSB 10	63.6738

Power Curve Fit

This program fits a power curve

$$y = ax^b \quad (a > 0)$$

to a set of data points

$$\{(x_i, y_i), i = 1, 2, \dots, n\}$$

where: $x_i > 0, y_i > 0$.

By writing this equation as

$$\ln y = b \ln x + \ln a$$

the problem can be solved as a linear regression problem.

Output statistics are:

1. Regression coefficients

$$b = \frac{n \sum (\ln x_i) (\ln y_i) - (\sum \ln x_i) (\sum \ln y_i)}{n \sum (\ln x_i)^2 - (\sum \ln x_i)^2}$$

$$a = \exp \left[\frac{\sum \ln y_i}{n} - b \frac{\sum \ln x_i}{n} \right]$$

2. Coefficient of determination

$$r^2 = \frac{[n \sum (\ln x_i) (\ln y_i) - (\sum \ln x_i) (\sum \ln y_i)]^2}{[n \sum (\ln x_i)^2 - (\sum \ln x_i)^2] [n \sum (\ln y_i)^2 - (\sum \ln y_i)^2]}$$

3. Estimated value $\hat{y}$ for given x

$$\hat{y} = ax^b$$

Note:

n is a positive integer and $n \neq 1$.

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
f CLEAR PRGM	00	R/S	08- 74
f LN	01- 14 1	f r	09- 14 23
X$\leftrightarrow$Y	02- 21	g x²	10- 15 0
f LN	03- 14 1	R/S	11- 74
Σ^+	04- 25	f LN	12- 14 1
GTO 00	05- 13 00	f $\hat{y}$	13- 14 22
f L.R	06- 14 24	g e^x	14- 15 1
g e^x	07- 15 1	R/S	15- 74

REGISTERS

R_0	R_1	R_2 n	R_3 $\sum \ln x_i$
R_4 $\sum (\ln x_i)^2$	R_5 $\sum \ln y_i$	R_6 $\sum (\ln y_i)^2$	R_7 Used

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f REG f PRGM	
3	Perform for $i = 1, \dots, n$:			
	Input x-value and y-value	x_i	ENTER	
		y_i	R/S	i
4	Calculate constants		GSB 06	a
			X$\leftrightarrow$Y	b
5	Calculate coefficient of determination		R/S	r^2
6	Input x-value and calculate $\hat{y}$	x	GSB 12	$\hat{y}$
7	Perform step 6 as many times as desired			
8	For new case, go to step 2.			

Example:

x_i	10	12	15	17	20	22	25	27	30	32	35
y_i	0.95	1.05	1.25	1.41	1.73	2.00	2.53	2.98	3.85	4.59	6.02

Solution:

$$a = 0.0262, b = 1.4556$$

$$y = .03x^{1.46}$$

$$r^2 = 0.9355$$

$$\text{For } x = 18, \hat{y} = 1.7609$$

$$\text{For } x = 23, \hat{y} = 2.5159$$

Keystrokes**Display**
f **REG** **f** **PRGM**

10 **ENTER** 0.95 **R/S** 1.0000
Keystrokes**Display**
12 **ENTER** 1.05 **R/S** 2.0000

:

:

35 **ENTER** 6.02 **R/S** 11.0000

GSB 06 0.0262

X $\leftrightarrow$ Y 1.4556

R/S 0.9355

18 **GSB** 12 1.7609

23 **GSB** 12 2.5159

Test Statistics

Chi-Square Evaluation

This program calculates the value of the χ^2 statistic for the goodness of fit test by the equation

$$\chi^2 = \sum_{i=1}^n \frac{(O_i - E_i)^2}{E_i}$$

where: O_i = observed frequency

E_i = expected frequency.

The χ^2 statistic measures the closeness of the agreement between the observed frequencies and expected frequencies.

Notes:

1. In order to apply this test to a set of given data, it may be necessary to combine some classes to make sure that each expected frequency is not too small (say, not less than 5).
2. If the expected frequencies E_i are all equal to some value E , then E should be calculated beforehand as

$$E = \frac{\sum O_i}{n}$$

and then input at each step as the expected frequency E_i .

KEY ENTRY	DISPLAY
[F] CLEAR [PRGM]	00
0	01- 0
[STO] 0	02- 23 0
[STO] 1	03- 23 1
[R/S]	04- 74
[STO] 2	05- 23 2
[=]	06- 41
[9] [x²]	07- 15 0
[RCL] 2	08- 24 2
[÷]	09- 71
[STO] [+] 1	10- 23 51 1
[RCL] 0	11- 24 0
1	12- 1
[+]	13- 51

KEY ENTRY	DISPLAY
[STO] 0	14- 23 0
[GTO] 04	15- 13 04
[STO] 2	16- 23 2
[=]	17- 41
[9] [x²]	18- 15 0
[RCL] 2	19- 24 2
[÷]	20- 71
[STO] [-] 1	21- 23 41 1
[RCL] 0	22- 24 0
1	23- 1
[=]	24- 41
[STO] 0	25- 23 0
[GTO] 04	26- 13 04

REGISTERS			
R ₀ n	R ₁ χ^2	R ₂ E_i	R ₃
R ₄	R ₅	R ₆	R ₇

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f PRGM R/S	0.0000
3	Perform for $i = 1, \dots, n$:			
	Input observed and expected frequencies	O_i	ENTER	
		E_i	R/S	i
4	Delete erroneous data	O_k	ENTER	
		E_k	GSB 16	
5	Display χ^2		RCL 1	χ^2
6	For new case go to step 2.			

Example:

O_i	8	50	47	56	5	14
E_i	9.6	46.75	51.85	54.4	8.25	9.15

Solution:

$$\chi^2 = 4.8444$$

Keystrokes

f **PRGM** **R/S**
 8 **ENTER** 9.6 **R/S**
 50 **ENTER** 46.75
R/S

Display

0.0000

1.0000

2.0000

:
:14 **ENTER** 9.15**R/S**

6.0000

RCL 1

4.8444

Paired t Statistic

Given a set of paired observations from two normal populations with means μ_1, μ_2 (unknown)

x_i	x_1	x_2	...	x_n
y_i	y_1	y_2	...	y_n

let

$$D_i = x_i - y_i$$

$$\bar{D} = \frac{1}{n} \sum_{i=1}^n D_i$$

$$s_D = \sqrt{\frac{n \sum D_i^2 - (\sum D_i)^2}{n(n-1)}}$$

$$s_{\bar{D}} = \frac{s_D}{\sqrt{n}}$$

The test statistic

$$t = \frac{\bar{D}}{s_{\bar{D}}},$$

which has $n - 1$ degrees of freedom (df), can be used to test the null hypothesis

$$H_0: \mu_1 = \mu_2.$$

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
f CLEAR PRGM	00	RCL 0	10- 24 0
=	01- 41	÷	11- 71
Σ+	02- 25	R/S	12- 74
GTO 00	03- 13 00	RCL 2	13- 24 2
g s	04- 15 25	1	14- 1
RCL 2	05- 24 2	=	15- 41
f √x	06- 14 0	GTO 00	16- 13 00
÷	07- 71	=	17- 41
STO 0	08- 23 0	f Σ-	18- 14 25
g x	09- 15 24	GTO 00	19- 13 00

REGISTERS

R_0 Used	R_1	R_2 n	R_3 ΣD_i
R_4 ΣD_i^2	R_5	R_6	R_7

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f REG f PRGM	
3	Perform for $i = 1, \dots, n$:			
	Input one pair of observation	x_i	ENTER	
		y_i	R/S	i
4	Delete erroneous data	x_k	ENTER	
		y_k	GSB 17	
5	Calculate t and df		GSB 04	t
			GSB 13	df
6	For new case, go to step 2.			

Example:

x_i	14	17.5	17	17.5	15.4
y_i	17	20.7	21.6	20.9	17.2

Solution:

$$t = -7.1554$$

$$df = 4$$

Keystrokes

Display

f **REG** **f** **PRGM**
 14 **ENTER** 17 **R/S** 1.0000
 17.5 **ENTER** 20.7
R/S 2.0000

:

15.4 **ENTER** 17.2
R/S 5.0000
GSB 04 -7.1554
GSB 13 4.0000

t Statistic For Two Means

Suppose $\{x_1, x_2, \dots, x_{n_1}\}$ and $\{y_1, y_2, \dots, y_{n_2}\}$ are independent random samples from two normal populations having means μ_1, μ_2 (unknown) and the same unknown variance σ^2 .

We want to test the null hypothesis

$$H_0: \mu_1 - \mu_2 = D$$

where: D is a given number.

Define

$$\bar{x} = \frac{1}{n_1} \sum_{i=1}^{n_1} x_i$$

$$\bar{y} = \frac{1}{n_2} \sum_{i=1}^{n_2} y_i$$

$$t = \frac{\bar{x} - \bar{y} - D}{\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \sqrt{\frac{\sum x_i^2 - n_1 \bar{x}^2 + \sum y_i^2 - n_2 \bar{y}^2}{n_1 + n_2 - 2}}}$$

We can use this t statistic, which has the t distribution with $n_1 + n_2 - 2$ degrees of freedom, to test the null hypothesis H_0 .

KEY ENTRY	DISPLAY
f CLEAR PRGM	00
STO 1	01- 23 1
g x̄	02- 15 24
STO 5	03- 23 5
RCL 4	04- 24 4
STO 6	05- 23 6
0	06- 0
STO 2	07- 23 2
STO 3	08- 23 3
STO 4	09- 23 4
R/S	10- 74
STO 0	11- 23 0
g x̄	12- 15 24
STO 3	13- 23 3
RCL 6	14- 24 6
RCL 1	15- 24 1
RCL 5	16- 24 5
GSB 45	17- 12 45
RCL 4	18- 24 4
RCL 2	19- 24 2
RCL 3	20- 24 3
GSB 45	21- 12 45
+	22- 51
RCL 1	23- 24 1
RCL 2	24- 24 2

KEY ENTRY	DISPLAY
+	25- 51
2	26- 2
-	27- 41
÷	28- 71
f x̄	29- 14 0
RCL 1	30- 24 1
g ȳ	31- 15 3
RCL 2	32- 24 2
g ȳ	33- 15 3
+	34- 51
f x̄	35- 14 0
x	36- 61
RCL 5	37- 24 5
RCL 3	38- 24 3
-	39- 41
RCL 0	40- 24 0
-	41- 41
x̄y	42- 21
÷	43- 71
R/S	44- 74
g x²	45- 15 0
x	46- 61
-	47- 41
g RTN	48- 15 12

REGISTERS

R ₀ D	R ₁ n ₁	R ₂ n ₁ , n ₂	R ₃ Σx, Σy, $\bar{y}$
R ₄ Σ x², Σ y²	R ₅ $\bar{x}$	R ₆ Σ x²	R ₇

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f REG	
3	Perform for $i = 1, \dots, n_1$:			
	Input x-value	x_i	$\Sigma+$	i
4	Initialize for y		GSB 01	0.0000
5	Perform for $i = 1, \dots, n_2$:			
	Input y-value	y_i	$\Sigma+$	i
6	Input D and calculate t	D	R/S	t
7	To find the means of x- and			
	y-values		RCL 5	$\bar{x}$
			RCL 3	$\bar{y}$
8	For a new case, go to step 2.			

Example:

x: 79, 84, 108, 114, 120, 103, 122, 120

y: 91, 103, 90, 113, 108, 87, 100, 80, 99, 54

$n_1 = 8$

$n_2 = 10$

$D = 0$ (i.e., $H_0: \mu_1 = \mu_2$)

Solution:

$t = 1.7316$

$\bar{x} = 106.2500$

$\bar{y} = 92.5000$

Keystrokes**Display**

```

f REG
79  $\Sigma+$  84  $\Sigma+$  ...
120  $\Sigma+$ 
GSB 01
91  $\Sigma+$  103  $\Sigma+$  ...
54  $\Sigma+$ 
0 R/S
RCL 5
RCL 3

```

8.0000
0.0000
10.0000
1.7316
106.2500
92.5000

One Sample Test Statistics For The Mean

For a normal population ($x_1, x_2, \dots, x_n$) with a known variance σ^2 , a test of the null hypothesis

$$H_0: \text{mean } \mu = \mu_0$$

is based on the z statistic (which has a standard normal distribution)

$$z = \frac{\sqrt{n} (\bar{x} - \mu_0)}{\sigma}$$

If the variance σ^2 is unknown, then

$$t = \frac{\sqrt{n} (\bar{x} - \mu_0)}{s}$$

is used instead. This t statistic has the t distribution with $n - 1$ degrees of freedom. $\bar{x}$ and s are sample mean and standard deviation.

KEY ENTRY	DISPLAY	KEY ENTRY	DISPLAY
f CLEAR PRGM	00	R/S	10- 74
STO 1	01- 23 1	g s	11- 15 25
g x	02- 15 24	RCL 0	12- 24 0
RCL 1	03- 24 1	x²y	13- 21
=	04- 41	÷	14- 71
RCL 2	05- 24 2	R/S	15- 74
f √x	06- 14 0	RCL 0	16- 24 0
x	07- 61	x²y	17- 21
STO 0	08- 23 0	=	18- 71
CLX	09- 34	GTO 00	19- 13 00

REGISTERS

R_0 $t \cdot s$	R_1 μ_0	R_2 n	R_3 Σx
R_4 Σx^2	R_5 Σy	R_6 Σy^2	R_7 Σxy

Example:

Suppose $\mu_0 = 2$, for the following set of data

$\{2.73, 0.45, 2.52, 1.19, 3.51, 2.75, 1.79, 1.83, 1, 0.87, 1.9, 1.62, 1.74, 1.92, 1.24, 2.68\}$

Solution:

test statistic $t = -.6919$ or $z = -0.5650$ if $\sigma = 1$.

Keystrokes

Display

f REG	
2.73 Σ+ 0.45 Σ+ ...	
2.68 Σ+	16.0000
2 f PRGM R/S	0.0000
GSB 11	-0.6919
1 GSB 16	-0.5650

STEP	INSTRUCTIONS	INPUT DATA/UNITS	KEYS	OUTPUT DATA/UNITS
1	Key in the program			
2	Initialize		f REG	
3	Perform for $i = 1, \dots, n$:			
	Input value	x_i	Σ+	i
4	Input μ_0	μ_0	f PRGM R/S	0.0000
5	Calculate t		GSB 11	t
	or			
5	Input σ and calculate z	σ	GSB 16	z
6	For new case, go to step 2.			

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