

Contemporary Social Science

Research Methods

A Practical Guide



**REVISED AND
ENLARGED
EDITION**

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NON-PARAMETRIC TESTS

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25.1 Introduction

In the development of modern techniques of statistical inference, the first tests to gain prominence and wide use were those which make a good many assumptions, and rather stringent ones, about the nature of the population from which the observations were drawn (Siegel, 1957). As already stated in the preceding chapter, some of the statistical techniques have certain rules or assumptions that must be satisfied if the results of the analyses based on them are to be valid. Many statistical tests and procedures are based on specific distributional assumptions. The assumption of normality is particularly common in classical statistical tests (Toothaker and Newman, 1994). However, non-parametric tests do not rely on the assumption of normality. The data are assumed to be a random sample. Many of the tests use the rank order of each observation rather than the data value as recorded.

By non-parametric, we mean a technique that is not based on a specific distributional assumption. In addition, most non-parametric tests may be used with non-numerical data, and it is for this reason that many of them are often referred to as "ranking tests" or "order tests" (Siegel, 1957). This chapter provides explanations on chi square (χ^2) and Kolmogorov-Smirnov (K-S) tests. These are examples of non-parametric statistical techniques often applied in the social sciences. While the chi-square goodness-of-fit

25.2 Chi-Square

The chi-square (χ^2) test is one of the most useful non-parametric statistical technique in the field of social sciences. An attractive feature of the chi-square goodness-of-fit test is that it can be applied to any univariate distribution for which you can calculate the cumulative distribution function (Siegel and Castellan, 1988). It handles data which are in form of frequencies, that is, where information is obtained by counting rather than by measurement. Also, it can handle data in weak measurement scales such as nominal and ordinal scales. χ^2 test helps in determining whether the observed frequencies in a distribution differ significantly from the frequencies which might be expected according to some assumed theory or hypothesis.

Chi-Square–One– Sample Test

In so far as we are interested in determining the extent of fit of theoretical, hypothesised or expected distributions with observed distributions, χ^2 one-sample test is really a goodness of fit test. The χ^2 one–sample test is given by:

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

Where : O_i are the observed values
 E_i are the expected values
 It can be written simply as:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

From the formula, it is clear that if agreement between the observed and expected frequencies is close, the difference $O - E$ is small and so χ^2 will be small. And if χ^2 is small, there is really high probability that the differences may have occurred by chance. To understand this idea further there is need for examples.

Example 1

A survey of households in two cities A and B yielded the following room densities (persons per room):

A	2, 4, 6, 3, 8, 12, 5, 4, 6, 7, 1, 2, 9, 8, 11, 14, 3, 2, 1, 12
B	1, 8, 12, 14, 9, 6, 8, 16, 12, 4, 5, 6, 7, 9, 8, 15, 13, 7, 10, 12

Test the hypothesis that room densities differ significantly as between the two towns by using the chi-square test.

Step 1

Restate the observed and expected values

Observed: 2, 4, 6, 3, 8, 12, 5, 4, 6, 7, 1, 2, 9, 8, 11, 14, 3, 2, 1, 12

Expected: 1, 8, 12, 14, 9, 6, 8, 16, 12, 4, 5, 6, 7, 9, 8, 15, 13, 7, 10, 12

Step 2

State the null hypothesis

H_0 : There is no significant difference between room densities in cities A and B

H_1 : There is a significant difference between room densities in cities A and B.

Step 3

Set the level at which we may reject H_0 , say at 0.05

Step 4: Calculate Chi-Square

$$\chi^2 = \frac{(2-1)^2}{1} + \frac{(4-8)^2}{8} + \frac{(6-12)^2}{12} + \frac{(3-14)^2}{14} + \frac{(8-9)^2}{9} + \frac{(12-6)^2}{6} + \frac{(5-8)^2}{8} + \frac{(4-16)^2}{16} +$$

$$\frac{(6-12)^2}{12} + \frac{(7-4)^2}{4} + \frac{(1-5)^2}{5} + \frac{(2-6)^2}{6} + \frac{(9-7)^2}{7} + \frac{(8-9)^2}{9} + \frac{(11-8)^2}{8} + \frac{(14-15)^2}{15} +$$

$$\frac{(3-13)^2}{13} + \frac{(2-7)^2}{7} + \frac{(1-10)^2}{10} + \frac{(12-12)^2}{12}$$

$$\chi^2 = 1 + 2 + 3 + 8.64 + 0.11 + 6 + 1.13 + 9 + 3 + 2.25 + 3.2 + 2.67 + 0.57 + 0.11 + 1.13 + 0.07$$

$$+ 7.69 + 3.57 + 8.1 + 0$$

$$\chi^2 = 63.24$$

The degree of freedom is $K - 1 = 20 - 1 = 19$. The table value of χ^2 under 0.05 and with 19 degree of freedom is 30.144 (See Appendix IV). The calculated χ^2 (63.24) is, therefore, significant and, thus, we have no alternative than to reject H_0 . We then conclude that the samples are biased in so far as they differ significantly from the sample expected.

Chi-Square—Two—Sample Test

Problems involving χ^2 two-sample test and χ^2 K-sample tests are more common in urban and regional planning than those involving one-sample test. In a situation when a researcher has two or more nominal variables to compare with other two or more sets of

variables, the problem becomes a k-sample problem and the χ^2 test of homogeneity or independence can be used (Okoko, 2001). These are usually done with the aid of contingency tables (Morenokeji, 2006). Consider an example where it was hypothesised that there is no significant difference between men and women access to mortgage finance. To test this, let us assume that the data below were obtained from the records of 10 primary mortgage institutions (PMI).

Table 25.1: Pattern of Access to Mortgage Finance by Sex

Primary Mortgage Institution	Number of Housing Loan Beneficiaries	
	Male	Female
A	8	18
B	13	9
C	6	5
D	7	8
E	6	9
F	6	16
G	11	7
H	5	6
I	14	8
J	5	4

The case represented in Table 25.1 is a clear case of a χ^2 two-sample test because there are two samples – sample of women beneficiaries and sample of men beneficiaries.

Step 1

State the null hypothesis

The null hypothesis is that there is no significant difference between men and women access to mortgage finance. To test this, we have to obtain the χ^2 for two-sample test with the formula:

$$\chi^2 = \sum_{i=1}^n \sum_{j=1}^m \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Where the squared difference between observed (O_{ij}) and expected (E_{ij}) values are summed up over all rows (n) and over all columns (m).

Step 2

Obtain the expected (E_{ij}) values. As shown in the next table, this is obtained first by obtaining the column totals, the row totals and the grand total. In the table the grand total is 181. To obtain the expected value for any cell, we need to multiply its row total by its column total and divide by the grand total.

This may be denoted as:

$$\frac{RT \times CT}{GT}$$

where:

RT is row total

CT is column total

GT is grand total

Using this formula, the expected values for the observed values in columns one and two are obtained as follows:

Table 25.2: Obtaining Expected Values

No. of Male		No. of Female		Total
Observed	Expected	Observed	Expected	
8	(12.32)	18	(13.68)	26
13	(10.42)	9	(11.58)	22
6	(5.21)	5	(5.79)	11
7	(7.12)	8	(7.89)	15
6	(7.12)	9	(7.89)	15
6	(10.42)	16	(11.58)	22
11	(8.53)	7	(9.47)	18
5	(5.21)	6	(5.79)	11
14	(10.42)	8	(11.58)	22
5	(4.26)	4	(4.74)	9
81		90		171

$\frac{26 \times 81}{171} =$	12.32	$\frac{26 \times 90}{171} =$	13.68
$\frac{22 \times 81}{171} =$	10.42	$\frac{22 \times 90}{171} =$	11.58
$\frac{11 \times 81}{171} =$	5.21	$\frac{11 \times 90}{171} =$	5.79
$\frac{15 \times 81}{171} =$	7.12	$\frac{15 \times 90}{171} =$	7.89
$\frac{15 \times 81}{171} =$	7.12	$\frac{15 \times 90}{171} =$	7.89
$\frac{22 \times 81}{171} =$	10.42	$\frac{22 \times 90}{171} =$	11.58
$\frac{18 \times 81}{171} =$	8.53	$\frac{18 \times 90}{171} =$	9.47
$\frac{11 \times 81}{171} =$	5.21	$\frac{11 \times 90}{171} =$	5.79
$\frac{22 \times 81}{171} =$	10.42	$\frac{22 \times 90}{171} =$	11.58
$\frac{9 \times 81}{171} =$	4.26	$\frac{9 \times 90}{171} =$	4.74

The expected values thus obtained have been entered in parenthesis against their appropriate observed values in table 25.1. Once, we have been able to calculate expected values this way, the χ^2 can be calculated quickly as thus:

$$\chi^2 = \frac{(8-12.32)^2}{12.32} + \frac{(18-13.68)^2}{13.68} + \frac{(13-10.42)^2}{10.42} + \frac{(9-11.58)^2}{11.58} + \frac{(6-5.21)^2}{5.21} + \frac{(5-5.79)^2}{5.79} + \frac{(7-7.12)^2}{7.12} + \frac{(8-7.89)^2}{7.89} + \frac{(6-7.12)^2}{7.12} + \frac{(9-7.89)^2}{7.89} + \frac{(6-10.42)^2}{10.42} + \frac{(16-11.58)^2}{11.58} + \frac{(11-8.53)^2}{8.53} + \frac{(7-9.47)^2}{9.47} + \frac{(5-5.21)^2}{5.21} + \frac{(6-5.79)^2}{5.79} + \frac{(14-10.42)^2}{10.42} + \frac{(8-11.58)^2}{11.58} + \frac{(5-4.26)^2}{4.26} + \frac{(4-4.74)^2}{4.74}$$

Step 3

Determine the degree of freedom

For the χ^2 two-sample test, the degree of freedom is given by $(n-1)(m-1)$ where n refers to number of rows and m refers to number of columns. In our example, therefore, the degree of freedom is $(10-1)(2-1) = 9$. Thus, the degree of freedom we have for our contingency table is only 9.

With 9 degree of freedom, the χ^2 distribution table shows a value of 16.919 under 5 per cent level of significance. Our calculated χ^2 is, therefore, not significant at the 5 per cent level and we have to accept H_0 and conclude that there is no significant difference between male and female in access to mortgage finance. Any observed difference between them could have arisen by chance. Accordingly, the null hypothesis, H_0 , that male and female have equal access to mortgage finance is accepted.

Chi-Square – K – Sample Test

In several instances, the samples are more than two. When we apply χ^2 to problem where the samples are more than 2, we describe it as $\chi^2 K$ – sample test where $K \geq 3$. The methodology of obtaining the χ^2 k-sample test is very similar to that of χ^2 two-sample test. Consider the following example.

A planning student interested in recreation studies obtained the following data on attendance at recreation facilities in Ibadan.

Table 25.3: Attendance of Recreational Facilities by Income Groups

Income Group	Recreational Facilities			
	Amusement Park	Liberty Stadium	K/S Cinema	U.I. Zoo
Low		42	26	30
Middle		25	18	50
High		8	10	20

What is the hypothesis, H_0 , to be tested?

Test the hypothesis, using any appropriate technique.

The null hypothesis is that there is no difference in attendance at the recreation facilities as between the income groups. What this implies is that income does not influence attendance. We again set our significance level at 5 percent. Next, we obtain the expected values. We find the rows and columns totals as well as the Grand Total and then obtain

$$\chi^2 = \sum_{i=1}^n \sum_{j=1}^m \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

Table 25.4: Obtaining Expected Values for Attendance of Recreational Facilities by Income Groups

42(26.19)	26(18.86)	30(34.92)	12(30.03)	110
25(27.38)	18(19.71)	50(36.51)	22(31.40)	115
8(21.43)	10(15.43)	20 (28.57)	52(24.57)	90
75	54	100	86	315

$$\frac{110 \times 75}{315} = 26.19 \quad \frac{110 \times 54}{315} = 18.86 \quad \frac{110 \times 100}{164} = 34.92 \quad \frac{110 \times 86}{315} = 30.03$$

$$\frac{115 \times 75}{315} = 27.38 \quad \frac{115 \times 54}{315} = 19.71 \quad \frac{115 \times 100}{315} = 36.51 \quad \frac{115 \times 86}{315} = 31.40$$

$$\frac{90 \times 75}{315} = 21.43 \quad \frac{90 \times 54}{315} = 15.43 \quad \frac{90 \times 100}{315} = 28.57 \quad \frac{90 \times 86}{315} = 24.57$$

$$\begin{aligned} \chi^2 = & \frac{(42 - 26.19)^2}{26.19} + \frac{(26 - 18.86)^2}{18.86} + \frac{(30 - 34.92)^2}{34.92} + \frac{(12 - 30.03)^2}{30.03} + \frac{(25 - 27.38)^2}{27.38} \\ & + \frac{(18 - 19.71)^2}{19.71} + \frac{(50 - 36.51)^2}{36.51} + \frac{(22 - 31.40)^2}{31.40} + \frac{(8 - 21.43)^2}{21.43} + \frac{(10 - 15.43)^2}{15.43} \\ & + \frac{(20 - 28.57)^2}{28.57} + \frac{(52 - 24.57)^2}{24.57} \end{aligned}$$

$$\begin{aligned} \chi^2 = & 9.54 + 2.70 + 0.69 + 10.83 + 0.21 + 0.15 + 4.98 + 2.81 + 8.42 + 1.92 + 2.57 \\ & + 30.62 = 75.44 \end{aligned}$$

For the χ^2 K-sample test, the degree of freedom is obtained with the formula $(-1)(-1)$. In this example with 3 rows and 4 columns, the degree of freedom will be $(3-1)(4-1) = 6$. With 6 degree of freedom, table value of χ^2 under the 0.05 per cent level is 12.592. Our calculated χ^2 of 75.44 is, therefore, highly significant at 0.5 per cent level. We therefore reject H_0 and conclude that attendances differ significantly with income.

25.3 The Kolmogorov-Smirnov Test

Just like the χ^2 test, Kolmogorov-Smirnov (K-S) test is a non-parametric test. The duo enable us to achieve the same goal but with the important difference that while χ^2 handles data in form of frequencies, KS is designed for handling ordinal-type data. The basic enumeration of the K-S test is due to Kolmogorov (1941) and Smirnov (1943), hence Kolmogorov – Smirnov test (Abumere, n.d). Again, like χ^2 , the KS may be applied to one sample and two sample problems.

The K-S test is used to determine whether two underlying probability distributions differ from each other or whether an underlying probability distribution differs from a hypothesized distribution, in either case based on finite samples (Conover, 1999). In the one-sample case, the K-S test compares the empirical distribution function with the cumulative distribution function specified by the null hypothesis. The main applications are for testing goodness of fit with the normal and uniform distributions. The two sample K-S test is one of the most useful and general nonparametric methods for comparing two samples, as it is sensitive to differences in both location and shape of the empirical cumulative distribution functions of the two samples (Harwell, 1990).

One-Sample Kolmogorov-Smirnov Test

One-sample K-S tests whether a sample comes from a specified distribution. This method of testing hypothesis lays emphasis on the divergence between observed cumulative distributions and expected cumulative distributions. If the expected and observed values come from the same population, then there will not be much divergence between observed and expected values. The K-S concentrates on the largest of these divergences. For elaborate explanations on the usefulness of K-S, one-sample test in hypothesis testing, consider the following example.

Example

A survey of tertiary institutions in the southwest geo-political zone of Nigeria showed the following number of universities in the states surveyed:

Lagos	Oyo	Ogun	Ondo	Ekiti	Osun
3	3	5	2	1	4

Is it correct to say that universities are equally provided for in the six states?

The first thing to do is to set up a null hypothesis, H_0 , in the form

H_0 : Universities are not equally provided for in the six administrative states of southwest geo-political zone

H_1 : They are

In testing this hypothesis, we may set the level at which we may reject H_0 at 0.05.

In trying to test the hypothesis, using KS, we may follow these stages:

1. Specify the theoretical distribution, under H_0 . In this context, all the 6 states that were equally provided for would have a sample of 3 since there is a total sample of 18 to be shared among the 6 states equally.
2. Determine the theoretical cumulative distribution expected under H_0 as shown in Table 25.5.
3. Place the observed scores in form of proportions
4. Determine the cumulative distribution of the observed scores.
5. For each step on the cumulative distributions, subtract each observed value from each of its corresponding pair of theoretical value.
6. By inspection, determine D , which is given by the largest of the differences.
7. Refer to the percentage points of the K-S Distribution (Appendix V) If the calculated D is larger than the Table D , we may reject H_0 at the appropriate significance level.

These steps are summarised below

Table: 25.5: Stages in Computation of the K-S Test

	Lagos	Oyo	Ogun	Ondo	Ekiti	Osun
Theoretical Distribution	3/18	3/18	3/18	3/18	3/18	3/18
Observed values in proportions	3/18	3/18	5/18	2/18	1/18	4/18
Cumulative theoretical distribution	3/18	6/18	9/18	12/18	15/18	18/18
Cumulative observed scores	3/18	6/18	11/18	13/18	14/18	18/18
Difference (theoretical - observed)	0/18	0/18	2/18	1/18	1/18	0/18

$$D = 2/18 = 0.11$$

By reference to KS distribution table in Appendix V, with sample size (N) = 18, we find our calculated D to be significant at 0.05 level (two-tailed test) which is 0.309. We may therefore accept H_0 and conclude that universities are equally provided for in the six states of southwest geo-political zone of Nigeria.

Two-Independent-Samples K-S Test

Two-Independent-Samples Test compares two groups of cases on one variable. For example, a survey of two states in Nigeria showed the following number of open spaces in the towns surveyed:

State A: 4, 20, 3, 6, 9, 25, 13, 15, 2, 1, 12, 30, 45, 16, 22
 State B: 3, 25, 1, 40, 45, 21, 10, 15, 30, 35, 50, 12, 8, 10, 15

Test the hypothesis that open spaces are equally provided for in the two states or test the hypothesis that open spaces differ significantly as between the two states by using the Kolmogorov and Smirnov test.

Class Interval	Tally	Frequency	Class Interval	Tally	Frequency
1 - 5	IIII	4	1 - 5	II	2
6 - 10	II	2	6 - 10	III	3
11 - 15	III	3	11 - 15	III	3
16 - 20	II	2	16 - 20	-	0
21 - 25	II	2	21 - 25	II	2
26 - 30	I	1	26 - 30	I	1
31 - 35	-	0	31 - 35	I	1
36 - 40	-	0	36 - 40	I	1
41 - 45	I	1	41 - 45	I	1
46 - 50	-	0	46 - 50	I	1
Total		15	Total		15

No. of open spaces	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50
State A (Proportions)	4/15	2/15	3/15	2/15	2/15	1/15	0/15	0/15	1/15	0/15
State B (Proportions)	2/15	3/15	3/15	0/15	2/15	1/15	1/15	1/15	1/15	1/15
State A (Cumulative)	4/15	6/15	9/15	11/15	13/15	14/15	14/15	14/15	15/15	15/15
State B (Cumulative)	2/15	5/15	8/15	8/15	10/15	11/15	12/15	13/15	14/15	15/15
Difference	2/15	1/15	1/15	3/15	3/15	3/15	2/15	1/15	1/15	0/15

$$D = \frac{3}{15} = 0.20 \text{ (i.e. } 11/15 - 8/15 \text{ or } 13/15 - 10/15 \text{ or } 14/15 - 11/15)$$

By reference to Appendix V with $n = 15$, we find that our D value of 0.20 is not significant even at 0.01 (both one tailed (8) and two-tailed (9)). We, therefore, accept H_0 and conclude that there is no significant difference in number of open spaces in the two states. That is, the two samples come from the same population.

The K-S test is more powerful in all cases than its non-parametric counterpart, the χ^2 test. Three main reasons are usually advanced for this. Firstly, the K-S needs not lose information through the combining of categories, as is the case with the χ^2 in so far as the K-S treats individual observations separately. Secondly, the fact that χ^2 has to combine adjacent categories when expected frequencies are small reduces its power considerably. Thirdly, the fact that for very small samples, χ^2 cannot be performed at all but K-S can. With the impressive power and other advantages of the K-S over the χ^2 , it is surprising that the latter has been used and more frequently than the former in social science research.

25.4 Conclusion

This chapter has demonstrated the application of the most useful non-parametric statistical techniques in the field of the social sciences; that is the χ^2 and the KS tests. Peculiar circumstances where the tests are more applicable were also discussed. The type of test to be adopted in testing a hypothesis between a given set of variables or data depends on the nature of the data and the scales of measurement of the data. While parametric statistics are generally more powerful than their non-parametric counterparts, the K-S tests in particular is as powerful as other parametric tests such as the student's t test.

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