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by Treska Ali

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Jonckheere-Terpstra Test

Treska Ali Othman

Email:

treskaali@gmail.com

Supervision:

Dr. Nazeera Sedeek Kareem

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Abstract

The Jonckheere-Terpstra (JT) test, is a nonparametric test based on ranks that does not necessitate assumptions regarding normality and homogeneity of variance. The JT test, tests the significant trend, if an increase in one variable results in changing in another by increasing or decreasing. This test employs Kendall rank correlation coefficients for the purpose of quantifying the intensity of the association between two variables. The test proves to be particularly valuable when dealing with instances in which the data does not follow a normal distribution or when the relationship between the variables is non-linear. In addition, the test is robust towards outliers, and it is plausible to employ limited sample sizes. When the presence of ties is observed, the application of Kendall's test against trend can be intricate, thus using the Terspstra test is a viable alternative. This test possesses the ability to identify disparities in both magnitude and order.

Tests relying on the median outperform in scenarios where the distribution possesses heavy tails. Similar to the univariate scenario, these outcomes are alike. The modified test outperforms the commonly utilized Jonckheere test in terms of both size and power. The utilization of the modified test is consequently advised in preference to Jonckheere's standard test, particularly in instances where precise permutations will be carried out. Jonckheere-Terpstra and Modified Jonckheere-Terpstra often detect trends that aren't present. In contrast, the NNT do not encounter this issue. But in comparison to the NNT tests, the tests appear to exhibit slightly superior performance. Findings suggest that the proposed test possesses superior efficacy in comparison to both Jonckheere-Terpstra and Terpstra-Magel tests, particularly when smaller sample sizes coincide with significant deviations in adjacent location parameters. The nonrandomized two-sided JT test exhibits a bias when it comes to the shifted location parameter. Conversely, the one-sided JT test demonstrates an absence of bias in relation to the family of distributions associated with the location parameter. For the purpose of comparing population medians rather than means, the JT test is an ideal statistical test when multiple independent samples are assumed to be arranged in an orderly manner. The JT test is favored over the Kruskal-Wallis H test due to its ability to compare and demonstrate significant disparities among population medians that are organized in a specific order. The Kendall's test for rank correlation between error and log sensitivity exhibits a certain level of pessimism and demonstrates marginal significance, the JT test resolves this statistical issue by examining the hypothesis that certain groups of log sensitivity data are arranged in order.

Keywords: Jonckheere-Terpstra, Nonparametric Test, Ordered Alternative Hypothesis

1. Introduction

1.1 Jonckheere-Terpstra Test

The Jonckheere-Terpstra test, which was put forth by Terpstra (1952) and Jonckheere (1954), is a nonparametric test based on ranks that does not necessitate assumptions regarding normality and homogeneity of variance. The Jonckheere-Terpstra test, tests the significant trend, if an increase in one variable results in changing in another by increasing or decreasing, between an ordinal explanatory variable and an ordinal or continuous response variable.
There is a modified version of the Jonckheere-Terpstra test (MJT) illustrated by Tryon and Hettmansperger (1973). Modified Jonckheere-Terpstra and Jonckheere-Terpstra tests are both used for analyzing nondecreasing ordered alternatives, but the Modified Jonckheere-Terpstra tests give weights to each Mann-Whitney statistic based on population order.

1.2 Assumptions

1. The dataset includes k random samples of sizes $n_1, n_2, ..., n_k$ taken from populations $1, 2, ..., k$ respectively.
2. The observations are independent, within and between samples.
3. The variable of interest is continuous.
4. The measurement scale is at least ordinal.

1.3 Procedure

First, we should make sure that the data is in an expected order.
The test hypothesis:

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

$H_1 : \mu_1 < \mu_2 < ... < \mu_k$, with at least one strict inequality

To compute the test statistic J :

$$J = \sum_{u=1}^{v-1} \sum_{v=2}^{k} U_{uv}$$

Where U_{uv} is the Mann-Whitney count between samples u and v:

$$U_{uv} = \sum_{i=1}^{n_u} \sum_{j=1}^{n_v} \phi(X_{iu}, X_{jv}),\ 1 \le u \le v \le k$$

At the α level of significance we reject H_0 if $J \ge j_\alpha$; otherwise, we don't reject it, where the constant j_α is chosen to make the type I error probability equal to α.

1.4 Large Sample Approximation

The large-sample approximation is based on the asymptotic $(\min(n_1, n_2, ..., n_k)$ tending to infinity) normality of J, suitably standardized.

$$Z_j = \frac{J - \mu_J}{\sigma_J}$$

Where $\mu_J = \frac{(N^2 - \sum_{j=1}^{k} n_j^2)}{4}$ and $\sigma_J^2 = \frac{[N^2(2N+3) - \sum_{j=1}^{k} n_i^2(2n_j+3)]}{72}$

The normal theory approximation is; reject H_0 if $Z_J \geq z_\alpha$; otherwise, do not reject.

1.5 Ties

In the case of having ties in the data, the variance is reduced to;

$$\sigma_J^2 = \left\{ \begin{array}{l} \frac{1}{72}\left[N(N-1)(2N+5) - \sum_{i=1}^{k} n_i(n_i-1)(2n_i+5) - \sum_{j=1}^{g} t_j(t_j-1)(2t_j+5)\right] \\ + \frac{1}{36N(N-1)(N-2)}\left[\sum_{i=1}^{k} n_i(n_i-1)(n_i-2)\right]\left[\sum_{j=1}^{g} t_j(t_j-1)(t_j-2)\right] + \frac{1}{8N(N-1)}\left[\sum_{i=1}^{k} n_i(n_i-1)\right]\left[\sum_{j=1}^{g} t_j(t_j-1)\right] \end{array} \right\}$$

Now, we can compute the adjusted J using;

$$J_{adj} = \frac{J - \left[\frac{N^2 - \sum_{j=1}^{k} n_j^2}{4}\right]}{(\sigma_J^2)^{1/2}}$$

2. Review

In 1952 (Terpstra) published a paper on “The Asymptotic Normality and Consistency of Kendall's Test Against Trend, When Ties Are Present in One Ranking”, that discusses the statistical properties of Kendall's test against trend, determines whether a data set exhibits a monotonic trend. Furthermore, in particular addressing the issue of data ties, which add complexity to the process of analysis. Terpstra asserts that, given specific circumstances, the test exhibits consistency and asymptotic normality. Additionally, he puts forth a new statistical measure to address situations involving ties. Kendall's test, aimed at utilizing to ascertain if a data set displays a monotonic trend. This test employs Kendall rank correlation coefficients for the purpose of quantifying the intensity of the association between two variables. The test proves to be particularly valuable when dealing with instances in which the data does not follow a normal distribution or when the relationship between the variables is non-linear. In addition, the test is robust towards outliers, and it is plausible to employ limited sample sizes. As stated by Terpstra in his paper, ties can manifest when there is an occurrence of the identical value in two or more instances of observation. When the presence of ties is observed, the application of Kendall's test against trend can be intricate, thus prompting Terpstra to develop a new statistic that can be employed. The test, as stated by him, exhibits consistency and asymptotic normality in specific circumstances, thus rendering it a valuable instrument for the examination of data featuring ties.

In 1954 (Jonckheere) published a paper on "A Distribution-Free k-sample Test Against Ordered Alternatives", Jonckheere introduced a non-parametric test for comparing k-samples of data, which does not require any assumptions about the underlying distribution. This approach differs significantly from conventional statistical methods. The objective of the proposed test is to discern variances in treatment outcomes among the various sequences of alternatives. This test possesses the ability to identify disparities in both magnitude and order. In the present investigation, the suggested examination is contrasted with alternative statistical approaches, including the one-way analysis of variance (ANOVA) and the F-test. These methodologies disregard the order arrangement of samples and lack the capacity to detect alternative hypotheses. Moreover, Jonckheere investigates the distributions of S for both small and large samples, in addition to analyzing the extremes of the Cumulant.

In 1997 (Choi and Marden) published a paper on "An Approach to Multivariate Rank Tests in Multivariate Analysis of Variance", that a describes the utilization of a class of multivariate rank-like quantities, which are utilized in the development of multivariate tests aimed at emulating well-known one-dimensional rank tests including Mann-Whitney/Wilcoxon two-sample tests, Jonckheere-Terpstra trend tests, and Kruskal-Wallis one-way variance tests. On the basis of qualitative orthogonal contrasts, one-way analysis of variance tests is formulated to enable the dissection of an aggregate statistic into components that are asymptotically independent. In addition to the customary normal-theory tests, the inclusion of componentwise rank tests is made, although the primary focus lies on tests founded on specific delineations of multivariate rank. According to a study of Pitman about efficiency, the latter tests exhibit superiority in cases where the distributions possess normal, slightly heavy tails, as well as light tails. Conversely, tests relying on the median outperform in scenarios where the distribution possesses heavy tails. Similar to the univariate scenario, these outcomes are alike.

In 1998 (Neuhauser, Liu, and Hothom) published a paper on "Nonparametric Tests for Trend: Jonckheere's Test, a Modification and a Maximum Test", that proposed a modification of Jonckheere's test. In contrast to Jonckheere's conventional test, the modified test has the ability to comprehensively address the level of the type I error and displays significantly greater efficacy when the precise permutation distribution is employed for inference. Using the modified test for inference based on asymptotic normality enhances its power to a certain extent. In addition to this, a comprehensive test is carried out which exhibits greater robust when confronted with an a priori unknown dose response shape. It is highly beneficial to possess robustness in the context of a closed testing procedure, particularly. Two sample data sets are subjected to testing. Fligner and Wolfe's test demonstrates greater statistical power for concave and umbrella shapes when compared to both Jonckheere's test and the modified test. In the situation involving linear and convex shapes, the test developed by Fligner and Wolfe exhibits diminished efficacy. The modified test outperforms the commonly utilized Jonckheere test in terms of both size and power. The utilization of the modified test is consequently advised in preference to Jonckheere's standard test, particularly in instances where precise permutations will be carried out. Maximum tests can be utilized to establish power equilibrium in scenarios wherein the dose-response shape is not known in advance. When dealing with a closed testing procedure that encompasses shapes which possess the potential to be either concave or umbrellashaped, it is highly recommended to employ this particular maximum test. This recommendation stems from the fact that both the Jonckheere test and the modified test fail to exhibit a significant level of effectiveness.

In 2003 (Terpstra a and Magel) published a paper on "A New Nonparametric Test for The Ordered Alternative Problem", that proposed a new nonparametric test for detecting nondecreasing ordered alternatives. Convergence rates may vary based on the distribution's "discreteness" and "skewness", as demonstrated by the simulation study. The results have indicated that the distribution of the NNT (the proposed test) exhibits a higher level of discreteness and skewness compared to the distributions of Jonckheere-Terpstra and Modified Jonckheere-Terpstra. In the context of ordered alternative cases, the tests of Jonckheere-Terpstra and Modified Jonckheere-Terpstra are typically regarded as possessing the highest level of statistical power. It has been demonstrated that in order to draw inferences that are approximate in nature, the asymptotic normality of the null distribution of the test statistic is established. Data sets from five real datasets were examined. The Modified Jonckheere-Terpstra test and the widely recognized NNT test are in concurrence for the initial three data sets. Regarding the remaining two data sets, we observe a deficiency in both the Jonckheere-Terpstra test and its modified version. As a result, these tests often detect trends that aren't present. In contrast to the Jonckheere-Terpstra tests, the NNT do not encounter this issue. In comparison to the NNT tests, the Jonckheere-Terpstra and Modified Jonckheere-Terpstra tests appear to exhibit slightly superior performance. In many situations, the NNT is quite similar. Ordered alternatives, in contrast, experience only a negligible decrease in power compared to non-ordered alternatives, owing to the significant reduction in power they possess. Consequently, the NNT protects against incorrect presumptions regarding the growth of relationships.

In 2008 (Ferdhiana, Terpstra and Magel) published a paper on "A Nonparametric Test for The Ordered Alternative Based on Kendall's Correlation Coefficient", that proposed a new method for testing the ordered alternative which is based on Kendall's tau. The powers of the Jonckheere-Terpstra test and the proposed test may vary depending on the location parameter arrangements, sample sizes, and underlying distributions. The results obtained from the simulation indicated that the power estimate of the proposed test was 0.20 greater than that of Jonckheere-Terpstra's test in certain instances, and 0.25 greater in a single instance. All findings suggest that the proposed test possesses superior efficacy in comparison to both Jonckheere-Terpstra and Terpstra-Magel tests, particularly when smaller sample sizes coincide with significant deviations in adjacent location parameters. In the context of Modified Jonckheere-Terpstra, this occurrence does not invariably manifest. Due to the fact that both the proposed test and the Modified Jonckheere-Terpstra test are derived by linearly combining weighted combinations of Mann-Whitney statistics, this phenomenon, undoubtedly, arises from the assignment of weights to the Mann-Whitney statistic.

In 2014 (Murakami and Lee) published a study on "Unbiasedness and biasedness of the Jonckheere–Terpstra and the Kruskal–Wallis tests", to find the unbiasedness and biasedness of test statistics in a testing hypothesis. This study presents an investigation of the unbiasedness/bias of Jonckheere-Terpstra's method for ordered alternatives. Based on the findings, it can be stated that the nonrandomized two-sided Jonckheere-Terpstra test exhibits a bias when it comes to the shifted location parameter. Conversely, the one-sided Jonckheere-Terpstra test demonstrates an absence of bias in relation to the family of distributions associated with the location parameter. Furthermore, it is crucial to consider the findings of this study as they strongly imply that in order to accurately interpret and draw meaningful conclusions from our nonparametric tests, it is imperative to incorporate a bias correction.

In 2015 (Ali, Rasheed, Siddiqui, Naseer, Wasim and Akhtar) published a paper on "Non-Parametric Test for Ordered Medians: The Jonckheere Terpstra Test", that describes when testing more than one independent sample in a clinical trial, nonparametric tests are often used. And by using the Kruskal-Wallis h test, you can identify significant differences between groups instead of one-way ANOVA. For the purpose of comparing population medians rather than means, the Jonckheere Terpstra test is an ideal statistical test when multiple independent samples are assumed to be arranged in an orderly manner. An examination of techniques for sterilizing ultrasound probes was employed in the implementation of the Jonckheere Terpstra test. To assess multiple population medians that are arranged in a specific order, the Jonckheere Terpstra test is suggested as a preferable alternative to the Kruskal-Wallis H tests. In the course of their experiment, they executed the Wilcoxon Signed Rank test and Kruskal-Wallis H test to compare the quantity of bacteria in each cleaning technique prior to and following the process. Following the determination that all three cleaning techniques exhibit notable distinctions, it may be of interest to delve into the order arrangement in which they vary in terms of the median bacterial quantities. Kruskal-Wallis H tests do not offer any valuable information regarding the orders of median bacterial counts, thereby rendering them an unsuitable option for gaining insight into such orderings. The most appropriate option for achieving this task would be to employ the non-parametric Jonckheere Terpstra test. The results indicate that the Jonckheere-Terpstra test is a more suitable choice in situations where there is a notable discrepancy in cleaning techniques and the ordered median bacterial counts hold significance. The Jonckheere Terpstra test is favored over the Kruskal-Wallis H test due to its ability to compare and demonstrate significant disparities among population medians that are organized in a specific order.

In 2018 (Jonckheere, Schirmer, and Langbein) published a study on "Jonckheere-Terpstra Test for Nonclassical Error Versus Log-Sensitivity Relationship of Quantum Spin Network Controllers", on the concordant trend between the error and another measure of performance, such as the logarithmic sensitivity, used in robust control to formulate a well-known fundamental limitation. Logarithmic normalization amplifies noise, making error versus logarithmic sensitivity less obvious compared to error versus sensitivity. Consequently, the Kendall's test for rank correlation between error and log sensitivity exhibits a certain level of pessimism and demonstrates marginal significance. This study demonstrates that Jonckheere-Terpstra's test resolves this statistical issue by examining the hypothesis that certain groups of log sensitivity data are arranged in order. There are frequently instances of concordant patterns observed between error and logarithmic sensitivity, a phenomenon that is profoundly anticlassical and challenges the established differentiation between complementary and supplementary sensitivity.

In 2023 (Sydney, Hung-Chih, Douglas, Chao, and Zhengyang) published a study on "A Nonparametric Alternative to The Cochran-Armitage Trend Test in Genetic Case-Control Association Studies: The Jonckheere-Terpstra Trend Test", to compare the power of Jonckheere-Terpstra (JT) trend test and the (CA) trend test in identification of novel genetic signals that make humans susceptible to complex diseases. The investigation findings were compared for the JT trend test and the CA trend test across a range of circumstances, encompassing diverse sample sizes (ranging from 200 to 2000), minor allele frequencies (ranging from 0.05 to 0.4), and modes of inheritance (ranging from dominant genetic model to recessive genetic model). Based on the outcomes of simulations and examination of actual data, it has been observed that the JT trend test generally exhibits higher, comparable, or lower efficacy when compared to the CA trend test, depending on the prevailing mode of inheritance being dominant, additive, or recessive. The JT trend test demonstrates superior performance over the CA trend test in all genetic models, particularly when the sample size is limited and the minor allele frequency is low. A JT trend test could potentially serve as a beneficial substitute for the CA trend test in specific scenarios where it exhibits a greater degree of statistical power. By doing so, it can enhance the identification and analysis of genetic signals linked to various human diseases.

3. Conclusion

This test employs Kendall rank correlation coefficients for the purpose of quantifying the intensity of the association between two variables. Tests relying on the median outperform in scenarios where the distribution possesses heavy tails. Similar to the univariate scenario, these outcomes are alike. The modified test outperforms the commonly utilized Jonckheere test in terms of both size and power. Findings suggest that the proposed test possesses superior efficacy in comparison to both Jonckheere-Terpstra and Terpstra-Magel tests, particularly when smaller sample sizes coincide with significant deviations in adjacent location parameters. The nonrandomized two-sided JT test exhibits a bias when it comes to the shifted location parameter. Conversely, the one-sided JT test demonstrates an absence of bias in relation to the family of distributions associated with the location parameter. The JT test is favored over the Kruskal-Wallis H test due to its ability to compare and demonstrate significant disparities among population medians that are organized in a specific order.

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