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Commentationes Mathematicae Universitatis Carolinae, Vol. 12 (1971), No. 1, 197--203

Persistent URL: `http://dml.cz/dmlcz/105337`

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12,1 (1971)

ASYMPTOTIC DISTRIBUTION OF RANK STATISTICS USED FOR MULTIVARIATE TESTING SYMMETRY

(Preliminary communication)

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This preliminary communication contains assertions on asymptotic distributions of statistics used for the nonparametric multivariate testing symmetry. The results are proved under the hypothesis of symmetry, a near alternative and a general alternative. The proofs are based on the corresponding theorems for univariate case and the theorem on convergence in distribution for vectors (see Theorem V.2.1 in [5]).

Let $\mathbf{X}_j = (X_{j1}, \dots, X_{jp})$, $1 \leq j \leq N$, be independent p -dimensional random variables and let R^+_{ji} be the rank of $|X_{ji}|$ in the sequence of absolute values $|X_{1i}|, \dots, |X_{Ni}|$. Put

$$\mathbf{S}_c = (S_{1c}, \dots, S_{pc})' ,$$

$$S_{ic} = \sum_{j=1}^{N} c_{ji}\, a_{Ni}(R^+_{ji}) \operatorname{sgn} X_{ji} , \quad 1 \leq i \leq p ,$$

with c_{ji} being regression constants, $a_{Ni}(j)$ scores and

$$\operatorname{sgn} x = \begin{cases} 1 & \text{if } x \geq 0 , \\ 1 & \text{if } x < 0 . \end{cases}$$

AMS, Primary 62E20, 62H10, 62G99 Ref.Ž. 9.77 , 9.74
Secondary -

By $\boldsymbol{\Sigma}_{pc}$ we denote the conditional matrix of $\mathbb{S}_c$ given $|X_{ji}| \dfrac{\operatorname{sgn} X_{ji}}{\operatorname{sgn} X_{j1}}$, $1 \leqq j \leqq N$, $1 \leqq i \leqq p$, under (1) given below and by $\boldsymbol{\Sigma}^-_{pc}$ the generalized inverse of $\boldsymbol{\Sigma}_{pc}$ (see [4]).

We are interested in an investigation of the asymptotic distribution of the statistics

$$Q_c = \mathbb{S}'_c \, \boldsymbol{\Sigma}^-_{pc} \, \mathbb{S}_c$$

under various systems of conditions.

The problem was solved for example in the papers of Puri and Sen [3], Patel [2] and Adichie [1]. The attention has been devoted to the case $c_{ji} = 1$ or $X_{j1} = X_{j2} = \ldots = X_{jp}$.

At first let us consider the following system of conditions for the distribution of $\boldsymbol{X}_1, \ldots, \boldsymbol{X}_N$:

(1)
- a) $\boldsymbol{X}_1, \ldots, \boldsymbol{X}_N$ are independent;
- b) $F_{1ik} = \ldots = F_{Nik}$, $i \neq k$, $1 \leqq i, k \leqq p$;
- c) $F_i(x) = 1 - F_i(-x)$, $1 \leqq i \leqq p$;
- d) F_i are continuous;
- e) $P(\operatorname{sgn} X_{j1} = v_1, \ldots, \operatorname{sgn} X_{jp} = v_p) =$
$= P(\operatorname{sgn} X_{j1} = -v_1, \ldots, \operatorname{sgn} X_{jp} = -v_p)$,
$1 \leqq j \leqq N$;
where F_{jik} and F_i, $1 \leqq j \leqq N$, $1 \leqq i \leqq p$, are the distribution functions of (X_{ji}, X_{jk}) and X_{ji}, respectively.

These conditions are fulfilled when $\boldsymbol{X}_1, \ldots, \boldsymbol{X}_N$ satisfy the multivariate hypothesis of symmetry (definition see [3]).

Let us denote by $\mathbb{D}_c = (d_{ik})_{i,k=1,\dots,p}$ the diagonal matrix with

$$d_{ii} = (\sum_{j=1}^{N} c_{ji}^2 \int_0^1 \varphi_i^2(u)\,du)^{-1/2} .$$

Further we shall suppose the covariance matrix Σ_c of $\mathcal{S}_c$ under (1) satisfies:

(2) If $\{\mathbb{D}_{c_\nu} \Sigma_{c_\nu} \mathbb{D}_{c_\nu}\}_{\nu=1}^{\infty}$ has a limit Σ for (4) given below with $c_{ji} = c_{ji\nu}$ then Σ is regular.

On the asymptotic distribution of Q_c under (1) we can state:

<u>Theorem 1</u>. Let (1),(2) and

(3) $\int_0^1 (a_{Ni}(1+[uN]) - \varphi_i(u))^2 du \to 0, \quad 1 \leqq i \leqq p,$

where φ_i is squared integrable and $[uN]$ is the largest integer not exceeding uN . Then the statistics Q_c are for

$$(4) \qquad \frac{\max_{1 \leqq j \leqq N} c_{ji}^2}{\sum_{j=1}^{N} c_{ji}^2} \longrightarrow 0 , \quad 1 \leqq i \leqq p ,$$

asymptotically χ^2-distributed with p-degrees of freedom.

Now we turn to another case. Under (6) given below the following conditions ensure that $X_1, \dots, X_N$ "nearly" satisfy the hypothesis of symmetry:

(5)

a) $X_1, \dots, X_N$ are independent;

b) X_{ji} has a density $f_i(x, \theta_{ji})$ where θ_{ji} is an unknown parameter;

c) $f_i(x, \theta)$ is absolutely continuous at

θ for almost all x, $1 \leq i \leq p$;

d) $\lim\limits_{\theta \to 0} \int \frac{(\dot{f}_i(x,\theta))^2}{f_i(x,\theta)}\, dx = \int \frac{(\dot{f}_i(x,0))^2}{f_i(x,0)}\, dx = I(f_i)$,

where $\dot{f}_i(x,\theta) = \frac{\partial f_i(x,\theta)}{\partial \theta}$, $1 \leq i \leq p$;

e) $\lim\limits_{\theta \to 0} \frac{1}{\theta}(f_i(x,\theta) - f_i(x,0)) = \dot{f}_i(x,0)$ for almost all x,

f) $f_i(x,0)$ are symmetric about 0, $1 \leq i \leq p$;

g) $F_{ik}(x, y, \theta_{ji}\ \theta_{jk})$ is continuous at $\theta_{ji} = \theta_{jk} = 0$ for all x, y, $1 \leq i, k \leq p$, with $F_{ik}(x, y, \theta_{ji}\ \theta_{jk})$ being the distribution function of (X_{ji}, X_{jk}) respectively.

Under (5) it can be stated about Q_c ($F_i(x, \theta_{ji})$ denotes the distribution function of X_{ji}):

Theorem 2. Let (5), (3) with φ_i, $1 \leq i \leq p$ being squared integrable, (2) with Σ_c being the covariance matrix of S_c under (1) with $\theta_{ji} = 0$, $1 \leq i \leq p$, $1 \leq j \leq N$, and

(6) $\max\limits_{1 \leq j \leq N} \theta_{ji}^2 \longrightarrow 0$, $\sum\limits_{j=1}^{N} \theta_{ji}^2 I(f_i) \leq b^2$, $0 < b^2 < +\infty$, $1 \leq i \leq p$,

hold. Then for (4) it holds.

$$\sup_x |P(Q_c < x) - G_p(x; \mu'_{\theta c} \Sigma_c \mu_{\theta c})| \to 0,$$

where the components of $\mu_{\theta c} = (\mu_{\theta c 1}, \dots, \mu_{\theta c p})'$ are given by

$$\mu_{\theta c i} = \sum_{j=1}^{N} \theta_{ji} c_{ji} \int \operatorname{sgn} x\ \varphi_i(F_i(|x|, 0) - F_i(-|x|, 0))\, \dot{f}_i(x, 0)\, dx$$

and where $G_p(x, \delta)$ is the distribution function of noncentral χ^2-distribution with p degrees of freedom and noncentrality parameter δ.

At the end the case of a general alternative will be considered. We shall suppose that $X_1, \dots, X_N$ satisfy only the following:

(7)
a) $X_1, \dots, X_N$ are independent;

b) the distribution function of X_{ji} is continuous.

Let us denote by Σ_c or $\Sigma_c^o = (G^o_{ikc})_{i,k=1,\dots,p}$ the covariance matrix under (7) or the expectation of Σ_{pc} under (7) respectively. Here we shall need also the following notation

$$D_c^o = (d^o_{ik})_{i,k=1,\dots,p} \quad ,$$

$$d^o_{ik} = \begin{cases} = d_{ii} & \text{if } \varphi_i \text{ satisfies (12), } i = k \ , \\ var^o \; S_{ic}) & \text{if } \varphi_i \text{ satisfies (13) but not (12),} \\ 0 & \text{if } i \neq k \ , \end{cases}$$

where var^o denotes var under (7).

Further we shall suppose that Σ_c^o satisfies:

(8) If there exists a matrix $\Sigma = (G_{ik})_{i,k=1,\dots,p}$ with the property, for every $\varepsilon > 0$ and $\eta > 0$ there exist an $N_{\varepsilon\eta}$ and $\delta_\varepsilon > 0$ such that the conditions

(9) $N > N_{\varepsilon\eta}$, $var\, S_{ic} > N\eta \max_{1 \le j \le N} c^2_{ji}$ if φ_i satisfies (13) but not (12) ,

$\operatorname{var}^{o} S_{ic} > \delta_{\varepsilon}^{-1} \max_{1 \leq j \leq N} c_{ji}^{2}$ if φ_i satisfies (12)

entail

$$| d_{ii}^{o} d_{kk}^{o} \sigma_{ikc}^{o} - \sigma_{ik} | < \varepsilon ,$$

then Σ is regular.

The condition (7) is weaker than (1) and (5). On the other side we restrict ourselves to scores of the form either

(10) $a_{Ni}(j) = E\, \varphi_i (U_N^{(i)}), \; 1 \leq j \leq N, \; 1 \leq i \leq p$,

or

(11) $a_{Ni}(j) = \varphi_i (\frac{i}{N+1}), \; 1 \leq j \leq N, \; 1 \leq i \leq p$,

with $U_N^{(i)}$ denoting the i-th order statistics in a sample of size N from the uniform distribution on and with φ_i defined on $(0, 1)$ that either

(12) has a bounded second derivative on $(0, 1)$

or

(13) has a form $\varphi_i = \varphi_{1i} - \varphi_{2i}$, where φ_{ki} is nondecreasing square integrable and absolutely continuous inside $(0, 1)$.

Theorem 3. Let (7) and (8) be satisfied, let the scores be given by (10) or (11) and φ_i, $1 \leq i \leq p$, defined on $(0, 1)$, satisfy the condition (12) or (13). Then for every $\varepsilon > 0$ and $\eta > 0$ there exist an $N_{\varepsilon\eta}$ and a $\delta_{\varepsilon} > 0$ such that (9) entails

$$\sup_{x} | P(Q_c < x) - P(U_c' \Sigma_c U_c < x) | < \varepsilon ,$$

where $U_c = (U_{1c}, \ldots, U_{pc})'$ has the normal distribution $(E\, S_c, \Sigma_c^{o})$.

R e f e r e n c e s

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(Oblatum 27.11.1970)