UPPER PERCENTAGE POINTS OF THE INDIVIDUAL ROOTS OF THE WISHART MATRIX

D. S. CLEMM
A. K. CHATTOPADHYAY
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APPLIED MATHEMATICS RESEARCH LABORATORY

PROJECT NO. 7071

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Upper Percentage Points of the Individual Roots of the Wishart Matrix

Let $S: n \times n$ be distributed as central Wishart matrix with $n$ degrees of freedom and let $E(S) = n I_p$, where $I_p$ is an identity matrix. Also, let $\theta_1 < \ldots < \theta_p$ be the roots of $S$. In this report, the authors gave exact upper $10\%, 5\%, 2.5\%$ and $1\%$ points of the distributions of $\theta_i (i = 1, 2, \ldots, p-1)$ for $p = 2(1)10$ and $n = (p+1)(1)20(2)30(5)50$. 

Aerospace Research Laboratories
Wright-Patterson AFB, Ohio 45433
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO
FOREWORD

This report was prepared for the Applied Mathematics Research Laboratory, Aerospace Research Laboratories by D. S. Clemm, A. K. Chattopadhyay and P. R. Krishnaiah under Project 7071, "Research in Applied Mathematics". The work of A. K. Chattopadhyay was performed at the Aerospace Research Laboratories while in the capacity of Technology Incorporated Visiting Research Associate under Contract F 33615-71-C-1463, T. I. Project No. 4262B.

In this report, the authors gave exact percentage points of the smallest and intermediate roots of the Wishart matrix.

The authors wish to thank Dr. V. B. Waikar for some helpful discussions.

They also wish to thank Miss Eva Brandenburg for typing the manuscript carefully.
ABSTRACT

Let $S: pxp$ be distributed as central Wishart matrix with $n$ degrees of freedom and let $E(S) = I_p$ where $I_p$ is an identity matrix. Also, let $\theta_1 < \ldots < \theta_p$ be the roots of $S$. In this report, the authors gave exact upper 10%, 5%, 2.5% and 1% points of the distributions of $\theta_i (i=1,2,\ldots,p-1)$ for $p=2(1)10$ and $n=(p+1)(1)20 (2)30(5)50$. 

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1. INTRODUCTION

The marginal distribution of the individual roots of the Wishart matrix are useful in testing certain statistical hypotheses. Pillai and Chang [7] constructed tables for the upper percentage points of the largest root of the Wishart matrix. Davis [2] gave a recurrence relation for the marginal densities of the individual roots by using results in [1]. Krishnaiah and Waikar [5] gave exact expressions for the cumulative distribution functions (c.d.f.'s) of intermediate roots. In this paper, we give exact upper 10%, 5%, 2.5% and 1% points of the smallest and intermediate roots of the Wishart matrix.

2. CUMULATIVE DISTRIBUTION FUNCTIONS OF THE INDIVIDUAL ROOTS

Let \( S: p \times p \) be distributed as Wishart matrix with \( n \) degrees of freedom and let \( E(S) = n I_p \), where \( I_p \) is the \( p \times p \) order identity matrix. Also, let \( \theta_1 < \cdots < \theta_p \) be the eigenvalues of \( S \). Then the joint density of \( \theta_1 < \cdots < \theta_p \) is given by

\[
f(\theta_1, \ldots, \theta_p) = k(p,n) \prod_{i=1}^{p} \exp\left(-\frac{\theta_i}{2}\right) \prod_{i>j}^p (\theta_i - \theta_j) \\
0 < \theta_1 < \cdots < \theta_p < \infty
\]

where

\[
r = \frac{(n-p-1)}{2},
\]

and

\[
k(p,n) = \frac{\pi^{p/2} (\frac{1}{2})^{np/2}}{\prod_{i=1}^{p} \Gamma((n+1)i/2) \Gamma((p+1)i/2)}.
\]

The following exact expression for the c.d.f. of the intermediate root \( \theta_s (1 < s < p-1) \) was given in Krishnaiah and Waikar [5]:

\[
P(\theta_s < x) = P(\theta_s < x) + k(p,n) \sum_{k=1}^{p-s} \rho(p,s,k_1,\ldots,k_s,0,x).
\]

\[
\rho(p,s,k_1,\ldots,k_s,0,x) =
\]

\[
\frac{1}{\prod_{i=1}^{n-s} \Gamma((n+1)i/2) \Gamma((p+1)i/2)}.
\]
where \((k_1, \ldots, k_s)\) is a subset of integers \((0, 1, \ldots, p-1)\) such that \(k_1 < \ldots < k_s\) and \(t_1 < \ldots < t_p\) is the subset complementary to \(k_1 < \ldots < k_s\) while \(\sum_{i=1}^{s} k_i\) denotes the summation over \(\binom{p}{s}\) possible subsets \(k_1 < \ldots < k_s\). Further \(\psi(y) = \exp(-\frac{y}{2})\) and the sign inside \(\sum_{i=1}^{p} k_i\) is positive or negative according as \(s(s+3)/2 + \sum_{i=1}^{s} k_i\) is even or odd. The function \(p(*)\) is defined by

\[ p(\psi; p, (k_1, \ldots, k_p), L, U) = \Lambda(\psi; 2m, (k_1, \ldots, k_{2m}), L, U) \quad \text{when} \quad p = 2m \quad (2.3) \]

and

\[ p(\psi; p, (k_1, \ldots, k_p), L, U) = \sum_{i=1}^{2m+1} (-1)^{i+1} \Gamma_k (L, U). \]

\[ G_i(\psi; 2m+1, (k_1, \ldots, k_{2m+1}), L, U) \quad \text{when} \quad p = 2m+1 \quad (2.4) \]

where

\[ \Lambda(\psi; 2m, (k_1, \ldots, k_{2m}), L, U) = \frac{k_j^i}{(f_{k_i}^j\psi(L, U))} i, j = 1, \ldots, 2m, 1/2, \]

\[ G_t(\psi; 2m+1, (k_1, \ldots, k_{2m+1}), L, U) \]

\[ = \frac{k_j^i}{(f_{k_i}^j\psi(L, U))} i, j = 1, \ldots, t-1, t+1, \ldots, 2m+1, 1/2 \]

for \(t = 1, \ldots, 2m+1\) while \(G_1(\psi; 1, k_1, L, U) = 1\). Further

\[ F_0^t(L, U) = \sum_{i=1}^{2m+1} (-1)^{i+1} \Gamma_k (L, U), \]

\[ F_t^t(L, U) = \sum_{i=1}^{2m+1} F_t (L, U) \theta^t \psi(\theta) d\theta, \]

\[ F_t^t(L, U) = \sum_{i=1}^{2m+1} x^t \psi(x) dx, \]

Also it is known (see[3,4]), that

\[ P[e_1 < x] = 1 - k(p, n)\rho(\psi; 1, r, c, \infty). \quad (2.5) \]

Using (2.2) and (2.5), we have constructed tables for the exact values of \(x\) for \(\alpha = 1(0.1)10, n = (p+1)(1)20(2)30(5)50, k = 1(1)(p-1)\) and \(\alpha = 0.01, 0.025, 0.05, 0.10\) where...
The values are given up to four decimal places and they may differ from actual values by at most one unit in the last decimal. As a check for the accuracy of the tables we have used the programs to compute the values of

\[ P[\theta_1 \leq x] + P[\theta_2 \leq x] + \ldots + P[\theta_p \leq x] \]

for some \( x \) and found them to differ from 1 in the 12th decimal only.
REFERENCES


The entries in the following table are the values of $x$ for different values of $N, p, S$ and $a$ where

$$p[a \leq x] = (1-a),$$

$$f(a_1, \ldots, a_p) = k(p, N) \prod_{i=1}^{p} [a_i \exp(-a_i/2)] \prod_{i>j} (a_i - a_j)$$

$$a_1 < \ldots < a_S < \ldots < a_p < \infty,$$

$$r = (N-p-1)/2,$$ and $k(p, N)$ is given by Eq. (2.1a).
### Table 1

**Upper Percentage Points of the Individual Roots**

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