THE "INEFFICIENCY" OF THE SAMPLE MEDIAN FOR FOR MANY FAMILIAR SYMMETRIC DISTRIBUTIONS[1]

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1. A lower bound. If the reciprocal of the (asymptotic) variance of an estimate is taken as a measure of its (asymptotic) efficiency, the sample median $\tilde{x}$ is often (asymptotically) less efficient than the sample mean $\bar{x}$, for many symmetric distributions familiar to statisticians. In fact, for a symmetric distribution having its maximum frequency at the point of symmetry, if $\tilde{x}$ is asymptotically less efficient than $\bar{x}$, then quite often $\tilde{x}$ is not so efficient as $\bar{x}$ at all, with the possible exceptions of very small samples. To show these facts, we derive a very simple, yet sharp, lower bound for the variance of the sample median.

Suppose that $F(x)$ and $f(x)$ are the cdf (cumulative distribution function) and pdf (probability density function) of a certain continuous distribution, and $f(x)$ is symmetric with respect to $x = \xi$, and $f(\xi) \geqq f(x)$ for all x. Let $\tilde{x}$ be the sample median of a sample of size $2n + 1$, then, where $C_n = (2n + 1)! / n! n!$,

$$\begin{aligned} (1) \qquad \operatorname{var} \tilde{x} &= \int_{-\infty}^{\infty} (x - \xi)^2 C_n [F(x)]^n [1 - F(x)]^n f(x)\, dx \\ &= \int_0^1 (x - \xi)^2 C_n F^n (1 - F)^n\, dF \\ &\geqq [f(\xi)]^{-2} \int_0^1 (F - 1/2)^2 C_n F^n (1 - F)^n\, dF \\ &= \{ 4 [f(\xi)]^2 (2n + 3) \}^{-1} . \end{aligned}$$

Equality holds for a rectangular distribution.

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2. Examples. It is well known that for a normal or rectangular distribution $\bar{x}$ is more efficient than $\tilde{x}$. We shall show that this is also true for many familiar symmetric distributions.

(1) Triangular distribution: $f(x) = 1 - |x|$, $|x| \leq 1$. Following (1), $\tilde{x}$ is less efficient than $\bar{x}$ for samples of sizes $2n + 1$ where $n > 1$. Direct computation shows that this is also true if $n = 1$.

(2) t-distribution. For a t-distribution with k degrees of freedom, $\tilde{x}$ is less efficient than $\bar{x}$ if (not necessarily only if)

$$\pi (k - 2) \Gamma^2(k/2) / 4 \Gamma^2((k + 1)/2) > (2n + 3)/(2n + 1).$$

For both $k= 2m$ and $k = 2m + 1$, the LHS (left hand side) of the above inequality is an increasing function of m. Computation shows, e.g., that the inequality holds if $k \geq 5$ and $n \geq 25$.

(3) Symmetric β-distribution. The pdf is given by [2, p. 244]

$$f(x) = \Gamma(2p)\Gamma^{-2}(p) x^{p - 1} (1 - x)^{p - 1},$$

$$0 < x < 1; p > 0.$$

$\tilde{x}$ is less efficient than $\bar{x}$ if

$$2^{4p - 4} (2p + 1) \Gamma^4(p) / \Gamma^2(2p) > (2n + 3)/(2n + 1) .$$

The LHS becomes smaller if p is replaced by p + 1, and tends to $\pi/2$ as p tends to oo. So it has a lower bound $\pi/2$. Hence the inequality holds for every $p > 0$ and $n \geq 2$.

(4) Cauchy type distribution. It is defined to be one with a pdf of the type $f(x) = C_\alpha/ (1 + |x|^\alpha)$, $-\infty < x < \infty$; $\alpha > 1$. If $\alpha = 2$, we obtain the well known Cauchy distribution for which $\tilde{x}$ is infinitely more efficient than $\bar{x}$. It would be interesting to examine whether or not $\bar{x}$ becomes more efficient as α increases. Now $\bar{x}$ has finite variance only if $\alpha > 3$. C_α and var $\bar{x}$ can be obtained by using contour integration [3, p. 118]. It follows that $\tilde{x}$ is less efficient than $\bar{x}$ if

$$x^2 \sin 3x / \sin^3 x > (2n + 3)/ (2n + 1),$$

where $x = \pi/\alpha$. The LHS is a decreasing function of x, so an increasing function of α. The least α's for which the LHS is equal to 5/3 and 1, the maximum and minimum of the RHS, are found to be 4.65 and 3.75 approximately.

3. Remarks.

(1) Not for all symmetric distributions is $\bar{x}$ more efficient than $\tilde{x}$. When the parent population has a Laplace distribution, e.g., $\tilde{x}$ is more efficient for all samples of odd sizes [1].

(2) If f(x) satisfies certain continuity conditions, $\tilde{x}$ has an asymptotically normal distribution and the asymptotic variance is $\{ 4 [f(\xi)]^2 (2n + 1) \}^{-1}$. Therefore if the sample size is not too small, the asymptotic variance is for all practical purposes a lower bound for var $\tilde{x}$. And if $\tilde{x}$ is asymptotically less efficient than $\bar{x}$, then $\tilde{x}$ is less efficient than $\bar{x}$ for all samples whose sizes are not too small.

References

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