**An Improved Minimum Mean Squared Error Estimate of the Square of the Normal Population Variance Using Computational Intelligence**

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**Abstract**

Building upon the commonly-employed approach by Searls, substantial work has addressed the use of the known coefficient of the normal population mean and the normal population variance. Subsequently, several attempts have also sought to formulate estimators for the population mean and variance for a more probable case of the population coefficient of variation being unknown. Across numerous real-world applications within basic science, economic, and medical research, an analyst is required to have an efficient estimator of the square of the population variance. As such, the purpose of the current investigation was to develop and test a more efficient estimator of the square of the population variance for a normal distribution, beyond that of the Minimum Mean Squared Error (*MMSE*) for the square of the population variance. The proposed approach, which incorporated a metaheuristic optimization algorithm of Computational Intelligence in its derivation, captures the information in the sample more fully by including the sample coefficient of variation with the sample mean and sample variance. Results of an empirical simulation study found comprehensive improvement in the relative efficiency of the proposed estimator versus the *MMSE* estimator compared to the square of the sample variance across all defined sample sizes and population standard deviations.

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**Keywords:** Empirical-simulation study; Minimum mean-squared-error estimator; Sample coefficient of variation.

**1 Introduction**

Substantial work accompanies the initial research conducted by Searls [1] regarding the estimator for the normal population mean with a known coefficient of variation. In these extensions, to illustrate, focus has often been directed toward utilizing the known coefficient of variation and kurtosis as presented in Khan [2], Gleser and Healy [3], Searls and Intarapanich [4], Arnholt and Hebert [5], and Sahai [6]. Subsequently, numerous approaches have been motivated by a need to formulate estimators for a population mean and variance for a more probable case of the population coefficient of variation being unknown, appearing in Sahai et al. [7], Richards et al. [8], Sahai et al. [9], and Lovric and Sahai [10].

Several research applications exist wherein the analyst requires an efficient estimator of the square of the population variance, particularly within basic science, economic, and medical research (e.g., randomized clinical trials, comparative or cost-effectiveness analyses). In the context of an efficient confidence interval estimation problem for the mean of a lognormal distribution which is commonplace in these studies, the usual point estimator of the lognormal mean is , as described in Verma and Sahai [10], Skrepnek [11], and Skrepnek et al. [12]. This estimator utilizes the sample mean, , and the sample variance, *s2*, based upon a random sample from the resultant normal population, following log-transformation of the data, as: *x = log(y) ~ N(θ,σ2)*. The variance of the usual point estimator, , is:

 **(1)**

Notably, to estimate the variance expressed in **(1)**, the analyst is required to have an efficient estimator of the square of the normal population variance, *σ4*, which ultimately may lead to an efficient confidence internal estimation of the lognormal mean. In this context, following the approach of Searls [1], a class of estimators, *k·s4*, may be considered for estimating the square of the normal population variance to establish the Minimum Mean Squared Error (*MMSE*) for the square of the normal population variance, *σ4*.

Considering the prior issues, the purpose of the current research endeavor was to develop and test a more efficient estimator of the square of the population variance for a normal distribution, beyond that of the existing Minimum Mean Squared Error (*MMSE*) for the square of the population variance. The proposed approach, which incorporated a metaheuristic optimization (bat) algorithm of Computational Intelligence (CI) in its derivation, utilizes the information in the sample more fully by incorporating the sample coefficient of variation with the sample mean and sample variance. An empirical simulation study was conducted to assess the relative efficiency of the new proposed estimator, an Improved Mixed Minimum Squared Error (*IMMMSE*), and the *MMSE* compared to the square of the sample variance, *s4* (i.e., the sample counterpart estimator of the estimator of the square of the population variance, *σ4*). The empirical investigation consisted of the calculations of the actual Mean Squared Error (*MSE*) of the estimators *MMSE(s4)*, *IMMMSE(s4)*, and *s4*. For comprehensibility, results concerning the relative efficiency of *MMSE(s4)* and *IMMMSE(s4)* versus *s4* were expressed in percentage terms.

**2 The Proposition of an Efficient Estimator of the Square of a Normal Population Variance, *σ4***

When considering a normal population with a population variance, *N(θ, σ2)*, the process of obtaining the most efficient estimator of the square of the population variance, *σ4*, seeks to utilize to the fullest extent possible information contained in the random sample from this population of size *n ~ x1, x2, …, xn* that is summarized via the following two population statistics:

sample mean: 

sample variance:  **(2)**

By applying the well-known approach of using the sampling distribution of the sample variance, namely, , and given that the degrees of freedom, *df = (n – 1)*, the following are obtained:

 **(3)**

 where  **(4)**

 where  **(5)**

 where  **(6)**

As such, the subsequent lemma may be established.

**Lemma**. In the class of estimators *k·s4*, the Minimum Mean Squared Error (*MMSE*) estimator of *σ4* (i.e., the square of the normal population variance, *σ2*) is *MMSE1(s4) = k\*·s4*, given that:

 **(7)**

**Proof.** For the *MMSE* in the class of estimators *k·s4*, the optimal value of *k* is:



via the straightforward application of **(4)** and **(6)**.  **Q.E.D.**

Contextually, it is also important to note, too, that based upon **(4)** and **(6)**, the Relative Variance, , of the estimator *MMSE1(s4)* is:

 **(8)**

Building upon the aforementioned, an estimator based upon the sample coefficient of variation intended to more fully utilize the information within a given sample (i.e., the proposed estimator) may be formulated based upon notation set as and the square of the sample coefficient of variation designated as *V*. In considering a new class of estimators, , it may be noted that:















 **(9)**

Thus, the *MMSE* estimator in the class is:



and, via **(9)**, the following is obtained:

 **(10)**

Therefore, in the class of estimators , the *MMSE* of *σ4* (i.e., the square of the normal population variance *σ2*) would be:

 **(11)**

The relative variance, , of the estimator *MMSE2(s4)* is:



 **(12)**

Given the aforementioned, a ‘Mixed’ *MMSE* estimator of *σ4* may be expressed as:

 **(13)**

Subsequently, we may consider a class of estimators as follows, with ‘*m*’ defined as a non-negative integer:

 **(14)**

With the application of Computational Intelligence (CI) and simulation through a bat-inspired metaheuristic optimization algorithm described in Yang [13] and Khan et al. [14], it may be observed that optimum results for the non-negative integer in **(14)** are achieved with m = 10. Hence, it is proposed that an *Improved Mixed Minimum Mean Squared Error*, *IMMMSE(s4)*, is defined as follows, which is ultimately the focus of the empirical simulation study to evaluate its relative efficiency versus the Minimum Mean Squared Error, *MMSE1(s4)*, for the square of the population variance *σ4*:

 **(15)**

**3 Empirical Simulation Study**

**3.1 Methodology**

An empirical simulation study was undertaken to assess the efficiency of the proposed estimators developed in the current investigation relative to the square of the sample variance, which is the sample counterpart estimator of the square of the population variance, *s4*. This simulation consists in the calculations of the actual *MSEs* (Mean Squared Error) of the estimators *MMSE(s4)*, *IMMMSE(s4)*, and *(s4)*; results are presented as a Relative Efficiency for *MMSE(s4)* and *IMMMSE(s4)* versus *s4*, expressed in percentage terms.

The parent population sampled in the simulation study was defined as a normal distribution with illustrative values of its population standard deviation as *σ* = 0.20, *σ* = 0.25, *σ* = 0.30, *σ* = 0.40, *σ* = 0.45, and *σ* = 0.50. Sample sizes were defined as n = 6, n = 11, n = 21, n = 31, n = 41, n = 51, n = 71, n = 101, n = 202, and n = 303. Additionally, population means were also considered. While the population coefficient of variation is typically unknown, the empirical investigation utilized a value of 0.25 as *θ = 4σ*. Matlab 2010b code [The Mathworks Inc., Natick, Massachusetts] was developed and run with 51,000 replications. Again, results were presented as ‘Relative Efficiencies’:



 **(16)**

**3.2 Results**

Presented in Table 1, the relative efficiency of *IMMMSE(s4)* ranged from a low of 105.245 percent (*σ* = 0.25, n = 303) and a high of 647.400 percent (*σ* = 0.50, n = 6), while the relative efficiency of *MMSE(s4)* ranged from a low of 103.961 percent (*σ* = 0.25, n = 303) to a high of 602.842 percent (*σ* = 0.50, n = 6). Contingent upon this observation, the absolute difference between the *IMMMSE(s4)* and *MMSE(s4)* was at a maximum under conditions of a large population standard deviation and small sample size (*σ* = 0.50, n = 6) of 44.558 percentage points (*IMMMSE(s4)* = 647.400% versus *MMSE(s4)* = 602.842%), and at a minimum of 1.284 percentage points as sample sizes increased (*σ* = 0.25, n = 303) (*IMMMSE(s4)* = 105.245% versus *MMSE(s4)* =103.961%). Collectively, findings support the proposed efficient estimator, *IMMMSE(s4)*, under all combinations of sample size and population standard deviations as illustrated by the gains in efficiency compared to *MMSE(s4)*.

**Table 1. Relative Efficiencies of *IMMMSE(s4)* and *MMSE(s4)* Estimators Across Varying Sample Sizes and Population Standard Deviations**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Relative Efficiency Compared to *s4***  (in %) | | | | | | |
|  | **Population Standard Deviation** | | | | | | |
| **Sample Size,**  ***Estimators*** | ***σ = 0.20*** | ***σ = 0.25*** | ***σ = 0.30*** | ***σ =***  ***0.35*** | ***σ = 0.40*** | ***σ = 0.45*** | ***σ =***  ***0.50*** |
| **n=6** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 572.647 | 589.823 | 581.617 | 566.441 | 576.710 | 575.012 | 602.842 |
| *IMMMSE (s4)* | 610.154 | 632.370 | 618.729 | 600.219 | 613.251 | 610.602 | 647.400 |
| **n=11** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 279.938 | 280.518 | 275.787 | 276.921 | 277.612 | 273.618 | 278.949 |
| *IMMMSE (s4)* | 299.897 | 300.768 | 293.331 | 294.867 | 297.200 | 291.671 | 298.286 |
| **n=21** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 173.994 | 173.182 | 175.231 | 173.994 | 174.589 | 175.884 | 173.907 |
| *IMMMSE (s4)* | 185.468 | 184.363 | 187.331 | 185.462 | 186.445 | 187.671 | 185.608 |
| **n=31** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 146.215 | 146.519 | 147.752 | 145.377 | 147.658 | 147.858 | 147.194 |
| *IMMMSE (s4)* | 155.724 | 156.171 | 157.709 | 154.847 | 157.500 | 157.798 | 157.015 |
| **n=41** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 133.858 | 134.665 | 134.216 | 134.498 | 134.065 | 134.043 | 133.544 |
| *IMMMSE (s4)* | 142.700 | 143.695 | 142.786 | 143.485 | 143.183 | 142.600 | 142.017 |
| **n=51** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 127.318 | 127.266 | 126.125 | 126.344 | 127.451 | 126.449 | 127.669 |
| *IMMMSE (s4)* | 135.750 | 135.616 | 133.841 | 134.255 | 135.640 | 134.204 | 136.169 |
| **n=71** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 118.928 | 118.252 | 118.873 | 117.912 | 118.723 | 119.297 | 118.862 |
| *IMMMSE (s4)* | 126.057 | 125.197 | 125.937 | 124.673 | 125.814 | 126.713 | 126.122 |
| **n=101** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 112.786 | 113.153 | 112.765 | 113.122 | 112.425 | 112.863 | 112.502 |
| *IMMMSE (s4)* | 118.881 | 119.464 | 118.906 | 119.393 | 118.217 | 119.055 | 118.513 |
| **n=202** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 106.320 | 106.076 | 106.493 | 106.618 | 106.613 | 105.908 | 106.436 |
| *IMMMSE (s4)* | 110.102 | 109.589 | 110.483 | 110.614 | 110.391 | 109.248 | 110.199 |
| **n=303** |  |  |  |  |  |  |  |
| *MMSE (s4)* | 104.403 | 103.961 | 104.251 | 104.342 | 104.224 | 104.240 | 104.307 |
| *IMMMSE (s4)* | 106.239 | 105.245 | 105.808 | 105.952 | 105.907 | 105.793 | 106.072 |

*MMSE* = Minimum Mean Squared Error; *IMMMSE* = Improved Mixed Minimum Mean Squared Error (proposed estimator); *s4* = estimate of the square of the population variance; *n* = sample size; *σ* = population standard deviation

**4 Conclusion**

The current investigation sought to develop and test a more efficient estimator of the square of the population variance for a normal distribution, beyond that of the Minimum Mean Squared Error (*MMSE*) for the square of the population variance. By using the information in the sample more fully by via the sample coefficient of variation with the sample mean and sample variance, and applying a bat-inspired metaheuristic optimization algorithm of Computational Intelligence in its derivation, results of an empirical simulation study found improvements in relative efficiency comprehensively across all defined sample sizes and population standard deviations.

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