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**A Note on a Simple Tool
for the Comparison of
Several Estimates of
the Same Parameter**

How Tsao
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A NOTE ON A SIMPLE TOOL FOR THE
COMPARISON OF SEVERAL ESTIMATES OF THE
SAME PARAMETER

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A NOTE ON A SIMPLE TOOL FOR THE
COMPARISON OF SEVERAL ESTIMATES OF THE SAME PARAMETER

How Tsao and Tommy Wright

ABSTRACT

One basic step towards improving the quality of data produced by a data collection agency is to identify problem areas that require special attention. Comparisons with other comparable data sources, when possible, serve as a simple technique that can explore existing problems for one or both data collection systems.

In this paper, we suggest a simple tool which can be used in the comparison of several estimates of the same parameter and can provide some statements about the accuracy of the estimates vs. the target parameter. This tool, called the Maximum Ratio, gives a measure of closeness among the estimates and also serves as the basis of a test for determining when at least one of the estimates under comparison will be more than $(100)(\alpha)$ percent away from the true parameter where $0 < \alpha < 1$.

1. INTRODUCTION

One basic step towards improving the quality of data produced by a data collection agency is to identify problem areas that require special attention. Comparisons with other comparable data sources, when possible, serve as a simple technique that can explore existing problems for one or both data collection systems.

Martin (1981) has pointed out how the comparisons of different data series produced by federal statistics bureaus can make important contributions to the improvements in one or both data series and that precautions are needed to avoid judgments based solely on supposition rather than scientific evidence. In particular, Eckler and Pritzker (1951) considered such external data comparison as a beginning step in checking the adequacy of the frame. Depending on the scale of a study, different data series can be compared through various aspects of the data collection systems. Among the different data series, one may want to compare their activities (interviewing, collecting, processing, publishing, and dissemination), changes through time, error types (sampling and nonsampling), variables, and parameters. In many cases, priorities for comparison of data series must be set and analyses must be restricted to a limited number of estimates that may have the most significant impact to the users. The center of our discussion is on the comparison of estimates of the same key parameter.

A parameter is a characteristic of interest of a target population. We will focus on numerical characteristics. Parameters may be unknown and must be estimated. On a few occasions, one will find that there are

estimates from several different sources for the same (or similar) parameter(s).

For example, coal parameters are estimated by the Energy Information Administration of the U.S. Department of Energy, the Mine Safety and Health Administration of the U.S. Department of Labor, and the Bureau of the Census of the U.S. Department of Commerce. Similarly, petroleum parameters are estimated by the Energy Information Administration, the American Petroleum Institute, and the Bureau of the Census. Also, natural gas parameters are estimated by the Energy Information Administration, the American Gas Association, and the Bureau of the Census.

While the various agencies use different operational definitions and perform various data collection activities because of their different interests, sometimes it is possible to use available auxiliary information to adjust certain estimates so that they are comparable.

In this paper, we define the Maximum Ratio, a tool that can be of some use in assessing the accuracy of a collection of comparable estimates and in measuring the closeness of the estimates.

2. MAXIMUM RATIO

In its simplest form, the problem can be stated as follows: Given the positive estimates $\hat{\theta}_1, \hat{\theta}_2, \dots, \hat{\theta}_m$ of the unknown target parameter θ , how does one measure the closeness among the estimates and, if possible, obtain some statement of accuracy? Ratios might form the basis of the measure of closeness. Thus, if $\hat{\theta}_1$ is the estimate of primary interest produced by a particular agency, and $\hat{\theta}_2, \dots, \hat{\theta}_m$ are

comparable estimates produced by other agencies, then the particular agency may want to compute $\hat{\theta}_2/\hat{\theta}_1$, $\hat{\theta}_3/\hat{\theta}_1$, ..., $\hat{\theta}_m/\hat{\theta}_1$. This is very appealing, perhaps mainly because it is very simple. If the $m-1$ ratios are "close" to one, especially if the m estimates were obtained independently, the particular agency might infer that there is great reason to believe that its estimate $\hat{\theta}_1$, and indeed all of the estimates, are near the true value of θ . Unfortunately this is not necessarily the case as is shown in Figure 1. For it is possible that all of the estimates might be biased uniformly in the same direction and miss the target parameter.

Figure 1.

Thus, this procedure at best implies a measure of closeness for the m estimates based on θ_1 , but gives no information about the true value of θ .

To consider the closeness among a collection of estimates, we present another approach to the problem which is a refinement of the technique just discussed. First consider the case of $m = 2$ and assume that $\hat{\theta}_1$ and $\hat{\theta}_2$ are comparable positive estimates of θ . We then measure the closeness of the two estimates by computing the percentage that the absolute difference of the two estimates is of one of the estimates.

Thus,

$$\frac{|\hat{\theta}_1 - \hat{\theta}_2|}{\hat{\theta}_1} \times 100\%$$

represents the percentage that the absolute difference is of $\hat{\theta}_1$, and

$$\frac{|\hat{\theta}_1 - \hat{\theta}_2|}{\hat{\theta}_2} \times 100\%$$

represents the percentage that the absolute difference is of $\hat{\theta}_2$.

It is easy to verify that the absolute difference of the above two values is

$$\frac{(\hat{\theta}_1 - \hat{\theta}_2)^2}{\hat{\theta}_1 \hat{\theta}_2} \times 100\%.$$

For example, suppose that two estimates for θ from different sources are $\hat{\theta}_1 = 8$ and $\hat{\theta}_2 = 10$. Then,

$$\frac{|\hat{\theta}_1 - \hat{\theta}_2|}{\hat{\theta}_1} \times 100\% = 25\% \text{ and } \frac{|\hat{\theta}_1 - \hat{\theta}_2|}{\hat{\theta}_2} \times 100\% = 20\%.$$

Thus $\hat{\theta}_2$ is 25 percent away from $\hat{\theta}_1$; $\hat{\theta}_1$ is 20 percent away from $\hat{\theta}_2$; and the difference between the two percentages is $\frac{(10 - 8)^2}{(10)(8)} \times 100\% = 5\%$.

If the desire is to report only one number as a measure of closeness for the two estimates, one natural response is to use the larger percentage

because it gives an upper bound. Therefore, this measure of closeness is in a sense a conservative one.

Definition. We call this larger percentage the maximum ratio of $\hat{\theta}_1$ and $\hat{\theta}_2$, and define it formally as

$$C = \frac{|\hat{\theta}_1 - \hat{\theta}_2|}{\min(\hat{\theta}_1, \hat{\theta}_2)} \times 100\%$$

(Note: In some parts of this paper, we will find it convenient to refer to C as a decimal and not as a percent. Thus $C = 0.05$ will be equivalent to $C = 5\%$.)

For example, if $C = 25\%$, we say that $\hat{\theta}_1$ and $\hat{\theta}_2$ are within 25 percent of each other. The smaller the value of C , the closer the two estimates are to each other. Note that a small value of C for $\hat{\theta}_1$ and $\hat{\theta}_2$ does not imply that $\hat{\theta}_1$ and $\hat{\theta}_2$ are each close to the true value of θ . However, it is necessary for C to be small when both $\hat{\theta}_1$ and $\hat{\theta}_2$ are close to θ . The concept of the maximum ratio can be extended to m estimates $\hat{\theta}_1, \hat{\theta}_2, \dots, \hat{\theta}_m$ by taking C to be

$$C = \frac{\hat{\theta}_{(m)} - \hat{\theta}_{(1)}}{\hat{\theta}_{(1)}} \times 100\%$$

where $\hat{\theta}_{(1)} = \min(\hat{\theta}_1, \dots, \hat{\theta}_m)$ and $\hat{\theta}_{(m)} = \max(\hat{\theta}_1, \dots, \hat{\theta}_m)$. C has the property that

$$C \geq \max_{i,j} \frac{|\hat{\theta}_i - \hat{\theta}_j|}{\hat{\theta}_i} \times 100\%$$

Thus, C serves as an upper bound for the pairwise measurements of closeness in the sequence $\hat{\theta}_1, \dots, \hat{\theta}_m$ and does not depend on the assumption that $\hat{\theta}_1, \dots, \hat{\theta}_m$ are estimates of the same parameter.

3. MAXIMUM RATIO AS A TOOL FOR THE ASSESSMENT OF ACCURACY

Having considered the closeness among a collection of estimates, we now consider the closeness between the "true" value of θ and the sequence $\hat{\theta}_1, \dots, \hat{\theta}_m$ by means of the maximum ratio.

When the accuracy assessment statements of a data validation study or an error profile of the data collection system are not available, there usually exists no clue on the degree of accuracy of an estimate of primary interest. However, if a collection of positive comparable estimates is developed so that all the estimates purport to estimate the same parameter of interest, then an accuracy statement about the estimate of primary interest can be obtained.

Henceforth, let $\theta > 0$ be the parameter of interest and $0 < \alpha < 1$.

Definition. An estimate $\hat{\theta} > 0$ of θ is considered as unacceptable for θ for α if

$$\hat{\theta} < (1-\alpha)\theta \quad \text{or} \quad \hat{\theta} > (1+\alpha)\theta.$$

For example, $\hat{\theta}$ is unacceptable at $\alpha = 0.05$ if $\hat{\theta} < 0.95\theta$ or $\hat{\theta} > 1.05\theta$.

To say that $\hat{\theta}$ is unacceptable for θ for α means that $\hat{\theta}$ is more than $100\alpha\%$ away from θ . Hence to determine whether a single estimate is unacceptable at a given α requires total knowledge of θ . However, if the experimenter has a collection of estimates which includes the estimate of primary interest, then the following simple result gives some

information about the accuracy of the collection of estimates which will imply a statement of accuracy about the estimate of primary interest.

Lemma. For a given set of positive estimates $\{\hat{\theta}_1, \hat{\theta}_2, \dots, \hat{\theta}_m\}$ if

$$C > \frac{2\alpha}{1-\alpha}, \quad (1)$$

then at least one of the estimates for the parameter θ is unacceptable for α .

Proof: Recall that

$$C = \frac{\hat{\theta}_{(m)} - \hat{\theta}_{(1)}}{\hat{\theta}_{(1)}}.$$

By adding 1 to both sides of

$$\frac{\hat{\theta}_{(m)} - \hat{\theta}_{(1)}}{\hat{\theta}_{(1)}} > \frac{2\alpha}{1-\alpha}$$

we obtain

$$\frac{\hat{\theta}_{(m)}}{\hat{\theta}_{(1)}} > \frac{1+\alpha}{1-\alpha}$$

which implies that we have either

$$\hat{\theta}_{(m)} > (1+\alpha)\theta$$

or

$$\hat{\theta}_{(1)} < (1-\alpha)\theta.$$

This completes the proof.

The previous lemma says that if the experimenter has more than one estimate, then the test based on C can be used and some accuracy statement can be made. For example, suppose that $C = 0.80$ for m estimates of a given parameter. Then at least one of the estimates is more than $100\alpha\%$ away from θ for $\alpha < 0.29$ because $C > 2\alpha/(1-\alpha)$ is equivalent to $\alpha < C/(C+2) = 0.29$.

In general, if $C = C_0$ for m estimates of a particular parameter, then at least one of the estimates is more than $100\alpha\%$ away from θ for

$$\alpha < \frac{C_0}{C_0 + 2} \quad (2)$$

In other words, if one states an α that would not be tolerable and observes that $C/(C+2)$ exceeds α , then the experimenter knows that at least one of the estimates is unacceptable. Further investigation is needed by the experimenter to determine those estimates which might be in greatest error. If $C/(C+2)$ does not exceed α , then C merely serves as a measure of closeness as was explained previously. Note that (2) gives some information about the relative location of θ vs. the collection of estimates $\hat{\theta}_1, \hat{\theta}_2, \dots, \hat{\theta}_m$, and this is its chief importance.

The calculation of C enriches information needed in external data comparison. In practice, one may not know whether $\hat{\theta}_1, \dots, \hat{\theta}_m$ are estimates of the same parameter. Therefore a failure of the test in (1) indicates either that $\hat{\theta}_1, \dots, \hat{\theta}_m$ are estimates of the same parameter but at least one of the estimates is more than $100\alpha\%$ away from θ , or that $\hat{\theta}_1, \dots, \hat{\theta}_m$ are estimates of different parameters.

If one can identify that $\hat{\theta}_1, \dots, \hat{\theta}_m$ are estimates of the same parameter, then C becomes a meaningful measure of closeness and the test described in (1) will carry its full strength to provide accuracy statements.

4. AN EXAMPLE

In the following example, we illustrate the use of C using estimates from three different sources that report U.S. domestic coal production in 1977. The comparative estimates are given in Table I. All estimates are published and are final.

Table I. Comparison of estimates of the quantity of coal production for 1977 (quantity measure in thousand short tons)

i) Bureau of Census estimate	656,609 ^a
ii) Energy Information Administration estimate	697,205 ^b
iii) Mine Safety and Health Administration estimate	670,684 ^c

^aFrom "Bituminous Coal and Lignite Mining, 1977 Census of Mineral Industries" and "Anthracite Mining, 1977 Census of Mineral Industries", Bureau of the Census, U.S. Department of Commerce. Total production was obtained by adding the corresponding anthracite, bituminous, and lignite values.

^bFrom "Monthly Energy Review", Energy Information Administration, U.S. Department of Energy.

^cFrom "Injury Experience in Coal Mining, 1977", Mine Safety and Health Administration, U.S. Department of Labor. The estimate was originally reported as 670,683,811 short tons.

For more detail on the operational definitions for each data collection system and on how the various estimates were obtained, the reader is referred to the various publications that appear in the footnotes.

For the purpose of our discussion, we assume that the three estimates were used to estimate the same parameter and ideally they should be equal to each other. Suppose it is desired to take $\alpha = 0.025$.

Observe that

$$C = \frac{697,205 - 656,609}{656,609} = 0.06$$

By the previous Lemma, the test shows that $C = 0.06 > 0.05 = \frac{2\alpha}{1-\alpha}$. Thus at $\alpha = 0.025$ at least one of the three estimates is more than 2.5 percent away from the true value for the total U.S. Coal Production for 1977. When this occurs, additional investigation is needed. If we focus on estimates (ii) and (iii), we observe $C = 0.04 > 0.05 = \frac{2\alpha}{1-\alpha}$. Thus at $\alpha = 0.025$, we lack sufficient evidence to say that either (ii) or (iii) is more than 2.5 percent away from the true coal production. The reader is reminded that this does not imply that the two estimates are both within 2.5 percent of the true coal production.

In considering closeness among the estimates, we first give C for all possible pairs in Table II. Estimates (i) and (iii) have maximum ratio 0.02. From Table II and direct computation, we see that the maximum ratio for all three estimates is $C = 0.06$. In summary, all of the estimates are within 6 percent of each other while estimates (i) and (iii) are within 2 percent of each other.

Table II. Maximum ratio for each pair of estimates in Table I

Estimate	Estimate		
	(i)	(ii)	(iii)
(i)	///	0.06	0.02
(ii)	0.06	///	0.04
(iii)	0.02	0.04	///
/// Not applicable.			

5. REMARKS

The tool discussed in this paper is based on simple ideas. Since it is a tool, it is understood that it is not meant to do the complete task and that additional analysis will be needed. We believe that its use can facilitate any comparison of a collection of estimates for the same or similar parameters.

The intended contribution of (1) using the maximum ratios is to enable the experimenter to determine if there is a need to doubt his estimate based on scientific evidence. For if the test given in (1) indicates that at least one of $\hat{\theta}_1, \dots, \hat{\theta}_m$ is more than $100\alpha\%$ away from θ , the experimenter naturally asks, "Is my estimate (the estimate of primary interest) the one?"

The maximum ratio can also be applied to the two sides of a balance equation since the two sides of a realistic and workable balance equation with each entry replaced by appropriate estimates under investigation should be consistent to a certain degree. For example, a balance equation based on coal supply and disposition may be given by

$$\text{PRODUCTION} + \text{IMPORTS} = \text{DOMESTIC CONSUMPTION} + \text{EXPORTS} + \text{CHANGE IN STOCKS}$$

where "Change in Stocks" for year i is the year end stocks for year i minus the year end stocks for year $i - 1$. Here, a comparison between the totals on each side of a balance equation is a special case of our previous discussion for $m = 2$.

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