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Stanley Warner's Contributions to Statistically Balanced Information Technology

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ABSTRACT

Stanley Warner was widely known for the creation of the randomized response technique for asking sensitive questions in surveys. Over almost two decades he also formulated and developed statistical methodology for another problem, that of deriving balanced information in advocacy settings so that both positions regarding a policy issue can be fairly and adequately represented. We review this work, including two survey applications implemented by Warner in which he applied the methodology, and we set the ideas into the context of current methodological thinking.

KEY WORDS: Advocate scoring; Bayes' Theorem; Embedded experiment; Logistic regression; Survey analysis.

1. INTRODUCTION

Consider some recent controversial public or professional issues such as:

1. Should Canada endorse the North American Free Trade Agreement?
2. Should Quebec secede from the Canadian Federation?
3. Should the American Statistical Association adopt a program to certify statisticians?
4. Should smoking be banned in all restaurants in Ottawa?

The discussions and debates surrounding such issues often reflect highly polarized positions and "pro" and "con" arguments can strongly influence the opinions of individuals in the relevant populations of interest (*e.g.*, Canadian residents, ASA members, those who frequent restaurants in Ottawa). How to think about the presentation of such advocacy information in a balanced fashion is the topic of this paper.

It has often been said that only a small fraction of scientists make a truly novel research contribution once in their lifetime. Far fewer are responsible for multiple innovations. Stanley Warner is well-known for his creation and development of the randomized response model for surveys and that contribution has been widely hailed as a major development in statistics. What is less well known is his truly novel approach to the problem of balanced information in advocacy settings, on which he worked over a period of almost 20 years. As York University colleagues of Warner's at the time of his death in 1992, we know how seriously he took the obligation of statistics and statisticians to deal with such complex problems, and this work is one example of how he attempted to fulfill the obligation.

Our goal in this paper is to reintroduce Warner's ideas on the topic of balanced information in advocacy settings to the profession and to demonstrate how they fit into current survey practice and methodological thinking. In Section 2, we present his basic approach to the advocacy problem and we describe the statistical model he chose to focus upon (Warner 1975). In Sections 3 and 4, we discuss embellishments of the basic approach which he presented in subsequent papers (*e.g.*, see Warner 1981, 1984, 1985, 1987a), and we end by describing how Warner continued to pursue this research program up until the time of his death. In the process, we also stress the importance Warner attached to the application of his ideas.

2. THE BASIC PROBLEM

In a thoughtful, well-argued, yet provocative 1975 paper in the *Journal of the American Statistical Association*, Stanley Warner first presented the issue of measuring the impact of advocacy and balance on public opinion in connection with controversial issues. He did so by asking (and then answering) a pair of interrelated questions:

1. How can we estimate what the population would conclude on issue were each of the members provided with balanced information on the topic?

Warner's idea for answering this question was to use advocates to present summaries of arguments, both "pro" and "con," and to implement this in a factorial experimental design to different samples, and in the process achieve information about a balanced presentation. This then leads rather naturally to the second question:

2. How can we rate or score advocates in such settings?

He developed his formulation to answer the two questions simultaneously and, in doing so, he used *both* economical and statistical arguments. In this paper, we focus on the statistical portion of his arguments and refer the interested reader to Warner's paper for the economic details.

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Consider a pair of advocates or advocate teams whose role it is to brief individuals on the arguments associated with a controversial issue, H. Let $P(H)$ and $P(\bar{H})$ denote the proportion of the number of subjects in a given population "for" and "against" issue H. Let F_i and A_j denote "pro" and "con" presentations of advocates i and j, respectively for $i, j = 1, 2$. Let $P(H \mid F_i, A_j)$ and $P(\bar{H} \mid F_i, A_j)$ denote the number of subjects "for" and "against" issue H after hearing "pro" case from advocate i and "con" case from advocate j.

Warner defined the "net information" associated with F_i and A_j as

$$I(F_i,A_j) = ln[P(H \mid F_i,A_j)/P(\bar{H} \mid F_i,A_j)] - ln[P(H)/P(\bar{H})]. \quad (1)$$

Formula (1) is, of course, the logarithm of the Bayes factor, or what Good (1950) called the *weight of evidence*. While Warner recognized the evocative nature of the use of Bayes' Theorem here, his approach towards its use was purely frequentist.

Similarly, Warner defined the net information associated with "pro" and "con" cases of F_i and A_j, separately:

$$I(F_i) = ln[P(H \mid F_i)/P(\bar{H} \mid F_i)] - ln[P(H)/P(\bar{H})], \quad (2)$$

$$I(A_j) = ln[P(H \mid A_j)/P(\bar{H} \mid A_j)] - ln[P(H)/P(\bar{H})]. \quad (3)$$

The simplest assumption we can make relating the joint and marginal information quantities is that of independence of the "pro" and "con" cases,

$$I(F_i,A_j) = I(F_i) - I(A_j), \quad (4)$$

for $i = 1, 2$, and $j = 1, 2$. This assumption allows for some direct comparisons and, as we shall see, can be checked empirically.

In order to ensure that the advocates fairly treat both "pro" and "con" positions, Warner proposed to reward them on the basis of the sum of the net information they provided, *i.e.*

$$I(F_i) + I(A_j). \quad (5)$$

Economic theory, Warner argued, suggests that rewarding advocates in this fashion will lead them to at least strive to approximate the "unbiased information" associated with maximization under resource constraints. Thus we need to estimate the quantity in expression (5) along with the posterior odds implied by unbiased information:

$$P(H \mid F',A') \mid P(\bar{H} \mid F',A'). \quad (6)$$

"Balance" in design for data collection was the key to Warner's plan for estimation.

Warner's estimation plan was linked to his application. The controversial issue was the completion of the north-south Spadina Expressway in Toronto (Warner's home city). The original first section of the expressway was constructed in 1966 and, after much debate, the remainder of the project was canceled in 1971. Two years later, in 1973, Warner conducted a survey to learn what proportions of the population of registered voters of Metropolitan Toronto were for or against the original expressway plan. He took a random sample of 1,360 registered voters (1% of the corresponding population) divided into 8 equal subsamples of size 170. Two advocate teams prepared written positions, both "pro" and "con" the expressway, and one of each was included in the mailing. The order of presentation of the two written positions was also varied producing a $2 \times 2 \times 2$ experimental design with the first variable corresponding to who prepared the "pro" brief, the second to who prepared the "con" brief, and the third to the order of presentation ("pro" first or "con" first). Advocates were paid a basic fee and a larger amount was set aside to be paid to the team with the "best combined score." This is an excellent example of a factorial experiment embedded within a survey, and fits well with the spirit of embedding described in Fienberg and Tanur (1988).

Table 1

Sample Preferences for Spadina Expressway After Information by Advocates

Sample	i	j	k	For	Against	Undecided	Total	p_{ijk}	n_{ijk}
1	1	1	1	22	4	1	27	.846	26
2	1	1	2	18	9	2	29	.666	27
3	1	2	1	26	8	0	34	.764	34
4	1	2	2	21	11	1	33	.656	32
5	2	1	1	28	10	1	39	.736	38
6	2	1	2	14	11	1	26	.560	25
7	2	2	1	19	16	1	36	.542	35
8	2	2	2	19	17	2	38	.527	36

Source: Warner (1975).

In the cover letter, Warner asked respondents to return prepaid postcards indicating their preferences after reviewing the briefs. At the cut off date, 262 cards had been returned for a response rate of about 20%. The resulting data, in Table 1, are reproduced from Warner (1975).

Let p_{ijk} be the true proportion of the population "for" the expressway, in group (i, j, k). Then, with an additive term for order of presentation, the model of expression (1) becomes

$$ln[p_{ijk}/(1 - p_{ijk})] = ln[P(H)/P(\bar{H})] + I(F_i) - I(A_J) + D_k. \quad (7)$$

We now recognize expression (7) as a linear logit model, and the sampling scheme as product-binomial (ignoring the correction for the 0.2% sampling fraction). Of course when Warner did this work it preceded the existence of a monograph by Bishop, Fienberg, and Holland (1975), and was virtually concurrent with Nelder and Wedderburn's (1972) paper on generalized linear models. Thus his paper made no reference to the now extensive literature on logit and loglinear models.

To estimate the parameters in expression (7), Warner used weighted least squares, which yields both estimated coefficients and standard errors. Instead of dealing directly with the parameters in expression (7), he redefined them, in part to simplify computation and in part to aid in their interpretation:

$$\beta_1 = ln \frac{P(H)}{P(\bar{H})} + \frac{I(F_1) - I(A_1)}{2} + \frac{I(F_2) - I(A_2)}{2} + \frac{D_1 + D_2}{2}, \quad (8)$$

$$\beta_2 = I(F_1) - I(F_2), \quad (9)$$

$$\beta_3 = I(A_1) - I(A_2), \quad (10)$$

$$\beta_4 = D_1 - D_2. \quad (11)$$

The coefficient β_1 is an "intercept" or normalizing parameter, while β_2, β_3, and $\beta_2 + \beta_3$ measure the performance of the advocate teams, and β_4 measures the order effect. The net information provided by team 1 is $\beta_1 + .5(\beta_2 - \beta_3)$, and that provided by team 2 is $\beta_1 - .5(\beta_2 - \beta_3)$. The difference in net influence is thus $\beta_2 - \beta_3$.

Table 2

Weighted Least Squares Estimates of Theoretical Parameters

Parameter	Estimate	Approx. Std. Error
β_1	.712	.139
β_2	.648	.277
β_3	−.383	.275
β_4	.528	.274
$\beta_2 + \beta_3$	.264	.386
$\beta_1 + .5\beta_2 - .5\beta_3$	1.228	.266
$\beta_1 - .5\beta_2 + .5\beta_3$	.196	.215
$\beta_2 - \beta_3$	1.032	.395

Source: Warner (1975).

We reproduce Warner's estimation results in Table 2. We have double-checked the estimated values in Table 2 using the generalized model routines in $S+$, which utilize a version of iteratively weighted least squares (maximum likelihood in this case). Our logit model computations agree with Warner's to two decimal places. The residual deviance for this model equals 1.95 with 4 d.f., indicative of a remarkably good fit and offering strong support for the reasonableness of the independence assumption of expression (4).

In interpreting the results in Table 2, Warner noted that his economic analysis leads to the conclusion that the overall proportion of the population in favour of H when presented with unbiased information lies between the "pure" estimates for the 2 advocate teams, or in the present instances (.55, .77). These bounds correspond to the estimates in the 2nd and 3rd last lines of the table. As was clear from Table 1, no matter how we combine "pro" and "con" arguments, the majority in each subgroup favored completion of the expressway. Warner observed that we might be tempted to use $\hat{\beta}_1$ to produce a "best estimate" of the value of p corresponding to unbiased information, but he argued for a higher value, since Team 1 is superior to Team 2 in terms of total information, *i.e.*, $\hat{\beta}_2 - \hat{\beta}_3 > 0$. (The superiority of Team 1 is quite evident from a quick examination of Table 1 and does not require the full analysis.)

Warner ended his 1975 paper by pointing out all of the shortcomings of his small experiment, and his initial modelling efforts. What we can observe in retrospect is the way in which he was able to attack a very complicated public policy and survey problem using a simple but ingenuous model, as well as a rigorous estimation scheme built on the solid framework of a factorial experiment embedded in a sample survey, and then actually applying the methodology to produce an answer for a real problem.

It is worth noting that the first version of this paper was submitted for publication to *JASA* in June 1972, before Warner had actually carried out the empirical study on the Spadina Expressway controversy. Over two years passed before he resubmitted a revised version of the paper with the detailed example. Even well-known authors with innovative ideas often struggle to have their work published in major statistical journals, and a compelling empirical application is always of help.

3. EXTENSIONS AND A SECOND APPLICATION

Warner extended his balanced information approach in a second paper (Warner 1981), focusing on yet another application. This paper also signals a substantial change in Warner's thinking about statistics and probability, towards a subjective Bayesian approach and away from the classical approaches that he stressed in his early career. While the reported analyses are still frequentist in nature, Warner used, at least informally, the assessments of prior probabilities in a manner that fits rather naturally with the Bayesian formulation of expression (1) above.

In March 1972, the Canadian Federal Government announced a plan to build a second Toronto International Airport to the east of the city in Pickering, Ontario. This led to considerable controversy. In 1974, the government appointed a 3-person commission of inquiry. Warner carried out a concurrent but independent survey experiment. The question he posed was whether or not the Pickering Airport should be built before the year 2000. The general structure of the experiment was similar to the previous one on the Spadina Expressway controversy, but with some differences:

(i) This time his study population was economists.

(ii) He incorporated 2 "neutral" control sub-samples, which received neither "pro" nor "con" statements.

(iii) Respondents in the 8 experimental subsamples gave probability assessments (instead of 0-1 values) after assessing the advocacy positions. Those in the control groups also gave their probability assessment.

The test population was limited to those economists who belonged to the Canadian Economic Association or who could be identified as professors or lecturers in an economics department in a Canadian university. The survey was done via mail in two stages - the first identified those willing to read detailed briefs and "report opinions regarding an undisclosed federal project," and the second mailing divided those willing to participate into 10 subsamples, corresponding to the $2 \times 2 \times 2$ design of Section 2 plus the 2 control samples consistent of those who were asked for their opinions without briefs. A total of 726 economists participated in the experiment. In Table 3, we provide Warner's summary of the data for the 8 experimental subsamples in which he aggregated the posterior judgments into three groups according to whether they were substantially greater, nearly equal, or substantially less than 0.5. The data have been further aggregated across the 8 experiment groups. The results have been post-stratified according to whether the economists were professors, graduate students, or others. The data on "prior beliefs" come from a combination of the two control groups.

Table 3

Test Population Opinions on Pickering Airport

	Professors		Students		Others		Totals	
	Before Briefs	After Briefs	Before Briefs	After Briefs	Before Briefs	After Briefs	Before Briefs	After Briefs
For	9 (.143)	58 (.266)	9 (.257)	32 (.288)	11 (.180)	71 (.298)	29 (.182)	161 (.284)
Against	32 (.508)	155 (.711)	12 (.343)	72 (.648)	36 (.590)	160 (.672)	80 (.503)	387 (.683)
Undecided	22 (.349)	5 (.023)	14 (.400)	7 (.063)	14 (.230)	7 (.029)	50 (.315)	19 (.033)
Totals	63 (1.000)	218 (1.000)	35 (1.000)	111 (1.000)	61 (1.000)	238 (1.000)	159 (1.000)	567 (1.000)

Source: Warner (1981).

Note that all three groups had substantial negative opinions about the proposed airport, a posteriori, and that the differences in proportions of undecided between the experimental and control subsamples provide evidence that the advocacy briefs affected public opinion on the issue. Warner's formal statistical analysis of the data focused solely on the 8 experimental subsamples and utilized three variants of the formal model in expression (9) and the reparameterization of expressions (10) through (13):

(i) A logit structure similar to that in Warner (1975) based on the aggregation in Table 3, with "undecideds" in effect *imputed* as belonging in either the "pro" or "con" categories with probability 0.5. He called this a *Simple Aggregate Influence* model.

(ii) A more direct approach, which averaged the posterior assessments to get "aggregate proportions" in favor, and then treated these observed proportions as if they were binomial. He called this a *Weighted Aggregate Influence* model.

(iii) A two-stage model, which first used individual-level assessments breaking up the range of 0 to 1 into 17 levels, and then a "variable coefficient" regression model analysis. He referred to this as an *Average Disaggregate Influence* model.

Each analysis involved the use of a different form of weighted least squares to estimate the coefficients of interest.

In Table 4, we provide Warner's estimated coefficients under all three models and analyses. The results are similar across models and we can summarize the findings as follows:

(a) Team 2 clearly presented the strongest case ($\hat{\beta}_2$ and $\hat{\beta}_3$ are both positive and similar for all three columns).

(b) The estimated aggregate influence for Team 2 is $[\hat{\beta}_1 + .5(\hat{\beta}_2 - \hat{\beta}_3)] = -0.688$ corresponding to an estimated proportion in favor of the airport project of $\hat{p} = 0.355$.

(c) The disaggregate influence for Team 2 corresponds to an estimated proportion in favor of the airport project of $\hat{p} = 0.355$.

(d) The effect of order of presentation ($\hat{\beta}_4$) suggests that the brief appearing first in the enclosures had greater impact, and is consistent with the hypothesis that the "previous information favoring one position serves to discount new information against that position."

It turns out that the advisor for Team 1 felt that construction of the airport could not be defended and this seriously handicapped the "pro" efforts of Team 1 (something reflected in the estimates of β_2).

Table 4

Estimated Case Influence for Pickering Airport Experiment

Parameters	Simple Aggregate Influence	Weighted Aggregate Influence	Average Disaggregate Influence
β_1	−.857 (.093)	−.529 (.047)	−.736 (.065)
β_2	.485 (.188)	.337 (.097)	.462 (.132)
β_3	.147 (.188)	.146 (.097)	.187 (.132)
β_4	.313 (.186)	.209 (.095)	.307 (.129)
N	8	8	567

Source: Warner (1981).

4. OVERLAPPING INFORMATION

Warner worried that the information used in the Pickering Airport survey experiment involved an overlap between the "pro" and "con" cases, and there was also an overlap between the prior information available to the respondents and that presented by the advocates. He turned to this question several years later in Warner (1984, 1985), using a formal argument drawn from sampling theory.

Warner's idea was to consider N pieces of independent information being used to influence the proposition in question. Let Y_{ij} be the information content seen by the i-th person in the j-th piece of information. Then the prior odds for the i-th individual is

$$ln[p_i/(1 - p_i)] = \sum_{j \in A(i)} Y_{ij}, \tag{12}$$

where $A(i)$ is the collection of information seen by the i-th person prior to the presentation of the advocacy arguments. If $A(i)$ is empty, the initial log-odds for individual i should be 0 and thus $p_i = 0.5$.

The presented "pro" and "con" summaries draw on a subset, S, of m out of the N units. Suppose that participants act "rationally" and are not further influenced by data which has been seen before. The added information is then

$$\sum_{j \in S} Y_{ij} - \sum_{j \in A(i) \cap S} Y_{ij}. \tag{13}$$

If the m units of information are randomly selected without replacement from the total N, then this implies that we can treat the units in $A(i) \cap S$ as having been selected at random without replacement. We can treat the information from these overlapping units as following a hypergeometric distribution, and then we rewrite expression (1) as

$$I_i = m\bar{S}_i - m/N[p_i/(1 - p_i)] + \epsilon, \tag{14}$$

where I_i is the net information in the summary for the i-th individual, $\bar{S}_i$ is the average of the Y_{ij}'s for those data units $j \in S$, and the error term ϵ has zero conditional expectation, *i.e.*,

$$E\{\epsilon \mid [p_i/(1 - p_i)]\} = 0. \tag{15}$$

If we group subjects in an advocacy experiment exposed to the same "pro" and "con" briefs according to the values of p_i, then differences in net information should be related to $[p_i/(1 - p_i)]$ according to equation (14). Warner (1984) did this with additional simplifying assumptions and then analyzed the data from the Pickering experiment using assessments, the control groups and the Team 2 "pro" and "con" group, aggregated according to whether the respondent was a professor, a student, or other. The problem with using the data from the Pickering experiment is that we are in effect matching the individuals in the control group and the experimental group. What we really want is both the prior and the posterior assessments from the same individual (Warner 1987b).

Warner (1985, 1987a) returned to this theme of overlapping information, and he extended the model of expression (14) to take the form:

$$I_i = m\bar{S}_i + D_i r_i (Z_i - U_i), \tag{16}$$

where we have in effect replaced the coefficient $-m/N$ in expression (14) by $D_i r_i$, where $D_i \geq -1$ is a discount factor and $E(r_i) = m/N$. He then showed how to estimate the coefficients in this "random coefficients" regression model using generalized least squares, under various assumptions about the correlations among the quantities in (16).

He then applied the approach to a new set of data collected for a telephone survey of Carleton University students on the question of whether an elected Canadian Senate would be preferable to the existing appointed Senate. The interviewees were asked for their opinion on the issue expressed as a probability. They were then presented with a 6-sentence summary of a television debate on the topic, and asked to reconsider their probability assessments. Of the 417 participants, 316 gave prior probabilities different from 0 and 1. Of this group, 163 actually changed their assessment, and overall the average log-odds after the summary was virtually the same as it was before, but with a slightly smaller variance. Warner actually fit the model to the data, and the fitted equations were consistent with the notion of partial discounting of the information that they had already seen.

This was essentially Warner's last published contribution to the topic of balanced information assessment. At the time of his death, Warner was hard at work on a book-length manuscript whose title, *Statistically Balanced Information Technology*, suggests that he was attempting to synthesize and extend his ideas on the topic. Unfortunately, we have only been able to locate the early chapters of this book and these include just the introductory ideas on probability and regression that he expected to utilize in the later chapters.

5. FURTHER OBSERVATIONS

Warner's balanced information technology addresses the common problem of adversarial policy advocacy which may give rise to confusion and incorrect decisions because of imbalance in the presentation of the relevant facts. Examples of how the adversarial approach to dispute resolution in a legal setting could have distorting effects on questions of scientific fact are discussed in Fienberg (1989; see especially Appendix H by Vidmar). Among the responses to this situation have been repeated proposals to establish a science court to ensure balance in organizing the information relevant to a factual dispute and reaching decisions. In these proposals, the science court itself is an adversarial system, but based on well-defined procedures for the selection of issues, advocates, and judges designed to ensure impartiality and minimize the effects of personal bias. Warner's approach outlined here is a formal way to achieve precisely this kind of impartial result.

Warner's progression through the various stages of the work on balanced information was paralleled by a shift in his outlook on the foundations of statistics. He was trained as an economist and a classical statistician and his early statistical contributions, including the work on randomized response models, were all set in a frequentist statistical framework. The 1975 paper on advocate scoring represented his first step towards a subjectivist perspective and, with each successive paper, he added further elements of the Bayesian approach. In Warner (1979), Stan articulated this shift in thinking and it is especially apparent in the early chapters of his unpublished book. At the May 1992 annual meeting of the Statistical Society of Canada in Edmonton, his last public lecture, Stan described devices for the solicitation of probabilities that he had been developing for the book.

We can only speculate about how Stan's subjectivist synthesis of balanced information technology would have looked had he been able to complete the book. But given the depth of his commitment to the Bayesian approach and its recent methodological innovations, we expect that it would have included a hierarchical generalized linear model approach and utilized the latest developments in Markov Chain Monte Carlo simulation techniques.

Stanley Warner was constantly using the ideas from his research in the classroom and in reflecting back upon the work described here, he noted:

> ". . . almost all of the basic elements of an elementary statistics course are to some degree represented in these procedures, and the problems in modeling and design that are suggested could be considered at quite an advanced level", (Warner 1987b).

The statistics profession has lost a true innovator and a great educator. We count ourselves amongst Stanley Warner's students and we continue to learn from his work.

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