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Use of an Entropy Measure to Dichotomize a Variable

Sürekli Bir Değişkeni İkiye Ayırmak İçin Entropi Ölçüsünün Kullanımı

Jacques MARLEAU[1]
[1] Centre régional de santé et de services sociaux de la Baie-James, Chibougamau, Canada

Philippe GARVIE[2]
[2] CISSS de l'Outaouais, Gatineau,Canada

ABSTRACT

Numerous cut-off points have been identified in the literature for the 6-item Kessler Psychological Distress Scale (K6) used in Canadian population-based surveys. The rationale for selecting a cut-off point is often absent or poorly documented. The purpose of this paper is to present a new approach to identifying the rationale for the selection using only the distribution of K6 scores. An entropy measure was computed initially from the distribution of observed scores in the 25 K6 categories and subsequently for all possible cut-off points (two categories). This exercise was done using Quebec data from four cycles (2005, 2007-2008, 2009-2010 and 2013-2014) of the Canadian Community Health Survey (CCHS). The cut-off point selected is the one that provides a similar amount of information to that found for all 25 categories. The cut-off point selected for the four cycles of the CCHS was 5/6. This method underscores the importance of determining a cut off point empirically rather than adopting one simply because it has been used in previous studies. It also allows for straightforward comparison of results across different surveys and remains flexible enough to be applied to other scales.

Keywords: Psychological distress, K6, entropy, equitability index, cut-off point (threshold), Canadian Community Health Survey

ÖZ

Kanada'daki nüfus temelli araştırmalarda kullanılan 6 maddelik Kessler Psikolojik Sıkıntı Ölçeği (K6) için literatürde çok sayıda kesme noktası belirlenmiştir. Kesme noktasının seçimine ilişkin gerekçe çoğu zaman ya hiç belirtilmemekte ya da yetersiz biçimde belgelendirilmektedir. Bu makalenin amacı, yalnızca K6 puanlarının dağılımını kullanarak seçim gerekçesini belirlemeye yönelik yeni bir yaklaşım sunmaktır. Öncelikle, gözlemlenen puanların 25 K6 kategorisindeki dağılımından bir entropi ölçüsü hesaplanmış; ardından tüm olası kesme noktaları (iki kategori) için aynı hesaplama yapılmıştır. Bu uygulama, Kanada Toplum Sağlığı Araştırması (KTSA)'nın dört döngüsünden (2005, 2007–2008, 2009–2010 ve 2013–2014) elde edilen Quebec verileri kullanılarak gerçekleştirilmiştir. Seçilen kesme noktası, 25 kategorinin tamamı için elde edilen bilgi miktarına benzer düzeyde bilgi sağlayan noktadır. KTSA'nın dört döngüsü için belirlenen kesme noktası 5/6 olmuştur. Bu yöntem, bir kesme noktasının önceki çalışmalarda kullanılmış olmasına dayanarak benimsenmesi yerine, ampirik olarak belirlenmesinin önemini vurgulamaktadır. Ayrıca, farklı araştırmalar arasında sonuçların doğrudan karşılaştırılmasına olanak tanımakta ve diğer ölçeklere uygulanabilecek kadar esnek bir yapı sunmaktadır.

Anahtar Kelimeler: Psikolojik sıkıntı, K6, entropi, eşitlik indeksi, kesme noktası, Kanada Toplum Sağlığı Araştırması

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Sorumlu Yazar/Corresponding author: Jacques MARLEAU
E-mail: marleauj@videotron.ca
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Introduction

Over the past 30 years, several measurement instruments have been used to estimate psychological distress in the general population (Batterham et al., 2016; Henry & Crawford, 2005; Kessler et al., 2002, Kessler et al., 2003; Massé et al., 1998; McWilliams et al., 2003). The 6-item version developed by Kessler (K6) is frequently used in population-based surveys because of its brevity and strong psychometric properties.

The K6 was developed simultaneously with the longer 10-item version (K10) as part of a unified scale-development process intended to measure non-specific psychological distress in U.S. epidemiological surveys (Kessler et al., 2002; Kessler et al., 2003). Both scales were created using modern item response theory methods and load strongly onto a general distress factor reflecting emotional, cognitive and behavioral manifestations of distress. Despite containing fewer items, the K6 demonstrates psychometric properties comparable to those of the K10 across diverse populations (Gauvin et al., 2024; Kessler et al., 2002). It is now widely implemented internationally, translated into numerous languages, and incorporated into major population-based surveys, including the WHO World Mental Health Surveys (Kessler et al., 2010) and national health surveys in the United States and Australia (Furukawa et al., 2003; Kessler et al., 2002; Kessler et al., 2003).

It has also been included in many population-based surveys in Canada (National Population Health Survey (NPHS), Canadian Community Health Survey (CCHS) and Quebec Population Health Survey) (Orpana et al., 2009; Simpson et al., 2012). Several results have been published from these surveys in order to present a percentage of people in a situation of psychological distress since the late 1990s.[i,ii] Many thresholds have been used: 3/4 (Cott et al., 1999), 4/5 (ASSS de Laval, 2008; Marchand & Blanc, 2010; Stephens et al., 1999), 5/6 (Karunanayake & Pahwa, 2009; Pahwa et al., 2012), 6/7 (Cazale & Bernèche, 2012; Vézina et al, 2011), 7/8 (Chiu et al., 2017) 8/9 (Orpana, 2008; Orpana et al., 2009), 9/10 (Bérubé, 2008; Institut de la Statistique du Québec, 2003) and 12/13 (Mawani & Gilmour, 2010; Simpson et al., 2012).

This panoply of cut-off points is synonymous, for many, with confusion when it comes to selecting one to analyze data collected in the general population (for researchers, policy makers and clinicians alike). The rationale for selecting many of these cut-off scores is often unclear or relies on non-empirical considerations -for example, professional opinion, the adoption of thresholds used in previous studies, the choice of the top quintile of the score distribution, or the presence of a highly skewed distribution. In contrast, several cut-off points have been established or recommended by comparing K6 scores with an external criterion, typically a clinical diagnosis. In such cases, the most commonly applied approach is Receiver Operating Characteristic (ROC) curve analysis, a method widely used in clinical epidemiology to assess the diagnostic performance of cut-off scores for measurement instruments (Cairney et al., 2007; Ferro, 2019; Turgeon et al., 2022; Veldhuizen et al., 2007). A ROC curve is a graphical tool used to assess how well a test distinguishes between two groups. It plots the true-positive rate (sensitivity) against the false-positive rate (1 – specificity) across a range of cut-off points. The closer the curve lies to the upper-left corner of the graph, the better the test's discriminative ability. The area under the curve provides a summary measure of overall accuracy, with higher values indicating better performance (Hanley & McNeil, 1982). However, ROC analysis requires an external criterion, which is often unavailable in large-scale population surveys. At a population level, any empirically derived cut-off point is fundamentally a function of the score's own distributional properties. An ideal method should therefore be able to leverage these properties directly.

The objective of this research is to establish a cut-off point that takes into account all of the information in all of the K6 categories, using Quebec CCHS data collected in four cycles between 2005 and 2014. To achieve this, the Shannon entropy measure (Stewart, 2012) will be used to identify the level of organization/disorganization of information. The cut-off point chosen to arrive at two categories will be the one that has a similar equitability to the one initially derived from all categories (25 categories).

Methods

The purpose of this study is to use the information contained in the 25 response categories of the K6 (ranging from 0 to 24) to calculate an overall equitability value. Entropy is a probabilistic measure of uncertainty. This entropy value is then normalized into an equitability index that varies between 0 and 1, with these two numbers signifying low and high uniformity, respectively. A high equitability index (a result tending towards 1) is equivalent to equal numbers in each of the 25 categories of the K6, i.e., a perfect equirepartition. On the other hand, a low equitability (a result tending towards 0) is equivalent to a reduction in uncertainty and can be best understood as a

situation where almost all the respondents would fall into a single category.

First, the overall equitability index of the 25 categories will be calculated from the formulas below. The first formula (1) calculates the Shannon entropy (the H is the symbol of entropy). The second formula (2) divides the calculated entropy by the number of categories (i.e., 25 (S)) in order to obtain an index between 0 and 1 (the E refers to the notion of equitability).

$$H = -\sum_i \frac{n_i}{n} \ln \frac{n_i}{n} \quad (1)$$

$$E = \frac{H}{\ln(S)} \quad (2)$$

Then, an equitability index will be calculated in the same way for each of the possible cut-off points of K6 (0/1, 1/2 ... 23/24) using the same formulas. The objective is to determine the cut-off point that allows to obtain an equitability index relatively similar to the overall equitability index. The smallest absolute difference between the overall equitability index and the equitability measurements calculated for all cut-off points will be used to identify the threshold at which informational equivalence is approximately reached between the original 25-category structure and the dichotomized two-category structure.

Data for the analyses were obtained from the CCHS 2005, 2007-2008, 2009-2010 and 2013-2014. The CCHS is a federal cross-sectional survey that has been collecting information on health status, health services utilization and health determinants in the Canadian population since the early 2000s. Data were collected from individuals aged 12 years and older at the time of collection and living in private households (Statistique Canada, 2009). The CCHS data are available upon request. They must be ordered through Statistics Canada's Client Services, after which they are made accessible in a secure computing environment. The analyses will focus only on respondents from the province of Quebec, as they were the only ones to complete the module on psychological distress in all four cycles. The results for 2009-2010 will be presented first in order to fully understand the entropy measure. This survey period was chosen at random from the four. Then, the results for the other periods will be presented.

The K6 consists of six questions. The questions begin with the same wording: In the past month, how often have you felt: 1) nervous, 2) hopeless, 3) restless or fidgety, 4) so depressed that nothing could cheer you up, 5) that everything was an effort, and 6) worthless. Respondents' scores can therefore vary between 0 and 24, resulting in 25 categories. Scores of 0 and 24 represent a person who would have answered *never* and *all the time* to the six questions, respectively. In terms of reliability, Alpha coefficients range from .768 to .782, while those obtained from the Omega total range from .801 to .814. The two coefficients were reported in order to test, respectively, the tau-equivalent model and the congeneric model (Meyer, 2010).

The analyses rely on the distribution of respondents' total K6 scores, with sample sizes varying between 22,000 and 27,000 across the survey periods. Data will be calculated using the PAST (PAleontological STatistics) software, version 3.09 using the equitability index available in the diversity indices module.

Results

For 2009-2010, the number of respondents in each of the 25 categories is not uniform (Table 1, column 6). The calculated overall equitability index is 0.679 (95% CI: 0.675-0.683, column 6, last row). Scenarios 1 and 2 are used to better understand the concept of entropy by illustrating a maximum and minimum equitability. In scenario 1, the equitability index is 1 and corresponds to the situation where the same number of respondents would be found in all 25 categories (column 2, last row). It is 0 when the respondents are found exclusively in one category (column 4, last row).

Table 1

Simulated and Real Equitability Index Estimated from the Numbers of the 25 Categories of K6 During the Period 2009-2010

K6 categories	Scenario 1 (Maximum equitability)		Scenario 2 (Minimum equitability)		Actual data	
	Numbers	%	Numbers	%	Numbers	%
0	853	4	21 311	99.9	5 746	26.9
1	853	4	1	0*	3 300	15.5
2	853	4	1	0	3 939	18.5
3	853	4	1	0	1 837	8.6
4	853	4	1	0	1 911	9.0
5	853	4	1	0	1 071	5.0
6	853	4	1	0	1 037	4.9
7	853	4	1	0	611	2.9
8	853	4	1	0	548	2.6
9	853	4	1	0	311	1.5
10	853	4	1	0	251	1.2
11	853	4	1	0	177	0.8
12	853	4	1	0	177	0.8
13	853	4	1	0	105	0.5
14	853	4	1	0	75	0.4
15	853	4	1	0	74	0.3
16	853	4	1	0	53	0.2
17	853	4	1	0	35	0.2
18	853	4	1	0	24	0.1
19	853	4	1	0	15	0.1
20	853	4	1	0	13	0.1
21	853	4	1	0	7	0
22	853	4	1	0	4	0
23	853	4	1	0	3	0
24	853	4	1	0	11	0.1
equitability	1	100	0.004	100	0.679	100

* Percentages have been rounded to 0.

In Table 2, the equitability index and 95% CIs are presented for each of the K6 cut-off points (2nd column). The absolute differences between the overall equitability index (0.679) and all entropy figures for the 24 dichotomizations are shown in the last column (there are 25 categories, but 24 dichotomizations are possible). The smallest difference is 0.032, or 0.679 minus 0.647, and represents the 5/6 cut-off point.

Table 2

Calculated Equitability Index for All K6 Cut-Off Points and Absolute Difference with the Overall Equitability Index for the Period of 2009–2010

K6 cut-off points	Equitability calculated based on dichotomization	Absolute differences with the overall equitability
0 / 1	0.840 (0.832 – 0.849)	0.162
1 / 2	0.983 (0.980 – 0.986)	0.304
2 / 3	0.966 (0.961 – 0.970)	0.287
3 / 4	0.888 (0.880 – 0.895)	0.209
4 / 5	0.752 (0.742 – 0.762)	0.073
5 / 6	0.647 (0.636 – 0.659)	0.032
6 / 7	0.520 (0.508 – 0.533)	0.159
7 /8	0.431 (0.418 – 0.443)	0.248
8 / 9	0.338 (0.325 – 0.350)	0.341
9 / 10	0.278 (0.266 – 0.290)	0.401

(continued)

Table 2 (continue)

Calculated Equitability Index for All K6 Cut-Off Points and Absolute Difference with the Overall Equitability Index for the Period of 2009–2010

K6 cut-off points	Equitability calculated based on dichotomization	Absolute differences with the overall equitability
10 / 11	0.225 (0.213 – 0.236)	0.454
11 / 12	0.184 (0,173 – 0.195)	0.495
12 / 13	0.139 (0.129 – 0.150)	0.539
13 / 14	0.111 (0.101 – 0.121)	0.568
14 / 15	0.089 (0.080 – 0.098)	0.590
15 / 16	0.065 (0.057 – 0.074)	0.614
16 / 17	0.047 (0.040 – 0.055)	0.632
17 / 18	0.034 (0.028 – 0.041)	0.644
18 / 19	0.025 (0.019 – 0.031)	0.654
19 / 20	0.019 (0.014 – 0.024)	0.660
20 / 21	0.013 (0.009 – 0.017)	0.666
21 / 22	0.009 (0.006 – 0.140)	0.669
22 / 23	0.007 (0.004 – 0.120)	0.671
23 / 24	0.006 (0.003 – 0.010)	0.673

Analyses were also performed using information from Quebec respondents for the years 2005, 2007-2008 and 2013-2014. The overall equitability index are very similar to that of 2009-2010; they are 0.710 (95% CI: 0.706-0.713), 0.689 (95% CI: 0.685-0.693) and 0.673 (95% CI: 0.668-0.677), respectively. For the 2005 and 2007-2008 collection periods, the equitability index of 5/6 cut-off point is the closest to the overall K6 equitability index.[iii] The cut-off closest to the overall equitability index in 2013-2014 is 4/5 (Table 3). Note that the absolute difference between the overall equitability index and that of the 5/6 cut-off point is very close to that of the 4/5 threshold, with the difference being slightly lower for the latter threshold (0.044 compared to 0.059, see Table 3, last column).

Table 3

Absolute Difference Between the Overall Equitability Index and the Equitability Index of Certain Cut-Off Points for the Four Cycles of CCHS

K6 cut-off points	CCHS 2005	CCHS 2007-2008	CCHS 2009-2010	CCHS 2013-2014
3 / 4	0.220	0.208	0.209	0.185
4 / 5	0.104	0.084	0.073	0.044
5 / 6	0.006	0.015	0.032	0.059
6 / 7	0.124	0.142	0.159	0.170
7 / 8	0.218	0.233	0.248	0.251

Conclusion

Several cut off points have been used in studies based on Canadian population based surveys (particularly the NPHS and the CCHS) to estimate the proportion of individuals experiencing psychological distress. The method outlined in this article aims to only use information from all K6 categories by calculating an overall equitability index, an important concept in information theory. It is most useful when there are no external criteria measuring the same distress construct in population-based surveys. Comparing with equitability indices of all cut-off points, the 5/6 cut-off point was found to be the closest to the original equitability index of the K6 structure for the years 2005, 2007-2008, and 2009-2010. For the 2013-2014 period, the closest threshold to the original structure entropy is 4/5. It is important to recall that the 5/6 threshold equitability index was also very close to the overall equitability index. Given the very small difference in equitability between the two points and the results observed between 2005 and 2010, the selection of the 5/6 point also seems appropriate for the 2013-2014 cycle.

It is also possible that the threshold shifted slightly in 2013-2014. Indeed, during this period, there was an increase in the percentage of people with a score of 1 (about 19% rather than 15% for the other cycles) and a slight decrease in the percentages of people in all other categories. It would be interesting to see if these results are maintained in future cycles of the CCHS in Quebec.

Other authors had used the 5/6 threshold in the past (Karunanayake & Pahwa, 2009; Pahwa et al., 2012). This

threshold had been justified by its use in the Stephen et al. (1999) study. It is important to remember that this threshold was initially chosen arbitrarily. Also, the authors had justified it among other things based on the suggestions of a gerontopsychiatrist. Karunanayake and Pahwa's (2009) results were on older adults and Pahwa et al.'s (2012) results were on people from cultural communities. Therefore, it would be interesting to identify a cut-off point for each of the two populations from the entropy measure presented.

The equitability value of approximately 0.70 remained stable for the distress score across the four surveys. This finding implies more than mere consistency in results; it indicates that the fundamental distributional structure of psychological distress within the population was remarkably constant over the decade studied. An equitability index reflects the overall shape of a distribution—in this case, a highly skewed pattern with a large proportion of the population reporting very low distress and a smaller, graded proportion reporting higher levels. The stability of this index suggests that this underlying population-level pattern did not meaningfully change. In response to the question of whether the characteristic itself remains the same, our findings support the conclusion that, at the population level, the distributional properties of psychological distress are stable. This structural stability is a key prerequisite that validates the search for a single, robust cut-off point applicable across different time periods. It also highlights why an information-theoretic approach, which directly leverages these distributional characteristics, is so well-adapted for this problem, especially in survey contexts where external validation criteria like clinical diagnoses are unavailable.

The emphasis on replication of results in science has resurfaced recently (Leppink & Pérez-Fuster, 2016; 2017). Our results are therefore part of this tradition and their convergences give some credibility to the method employed. Also, it is important to recall that several authors have severely criticized the dichotomization of variables in recent years (Altman & Royston, 2006; MacCallum et al., 2002; Streiner, 2002). They all insist that dichotomization results in a loss of information and that consequently the ability of a study to detect a difference is greatly reduced. It is important to recall that this information-theoretic approach relies on all the information contained in the original K6 response structure. This procedure seeks to maintain informational equivalence between the original 25 category structure and the two category structure resulting from the dichotomization process (Shannon, 1948). By preserving the average level of uncertainty when converting a continuous variable into its dichotomized form, this technique minimizes the loss of information introduced by the transformation.

Further studies are needed using the general Quebec population to examine if this threshold will hold or change in the future. In addition, analyses could be done using data from other Canadian provinces when the K6 is available in some cycles of the CCHS. The proposed method may be useful in many circumstances that require the transformation of a dimensional (multi-category) variable into a dichotomous (two-category) variable. Also, it may be particularly useful in identifying a cut-off point for the K6 and other scales when there are no external criteria available in some population-based surveys.

Notes

[i]In this article, the term "threshold" is used interchangeably with the term "cut-off point.

[ii]Some authors have classified K6 scores according to several thresholds. The threshold presented in the introduction represents a level that the authors consider to be high or severe.

[iii]Results are available upon request.

[iv]The threshold used by Stephens et al. (1999) was 4/5 instead.

[v]Another study is mentioned by Karunanayake and Pahwa (2009) as a justification for their choice. It should be noted that it was conducted in Burkina Faso and not in Canada.

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