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PROBLEM OF THE EVALUATION OF RESEARCH PROCESSES − VERIFICATION OF CREDIBILITY OF STATISTICAL DATA

Abstract: The present paper presents the problem of the research work evaluation, with a special focus on reliability of statistical data used in tests. Besides situations, when an Author does not specify the source of data, this fact disqualifying the work, in some cases Authors are pleading the need to keep the source of data confidential. The only choice left to the Reviewer then is to accept the reliability of data or to reject it and refuse to review the study. How to eliminate this serious disadvantage from the scientific review process? An answer is provided in the hypothesis presented below. If the statistical data distribution follows Benford's law, the reliability of data used in the study can be confirmed with a probability close to certainty. The conclusion of the paper contains a proposal of assumptions for a system supporting Reviewers in preparing scientific reviews. The results of the empirical investigation, the assumptions of which were to support the process of verifying the hypothesis, are presented in an appendix.

Keywords: reliability of empirical data, Benford's distribution of the first digit frequency in statistical data.

Introduction

Evaluating scientific papers is a responsible task, since it has a significant influence on further development of research. Moreover, it contributes considerably to set new directions of studies. Scientific reviews provide an important support to Authors' research processes. From an Author's point of view, a review is a source of the first reader's opinion, an evaluation of the scientific methodology and of the analytical instruments selection justifiability, and – in case of empirical studies – a verification of the statistical sampling method or of the questionnaire-based survey correctness. Scientific evaluation verifies test results and most typically it does not address the research process, the experiment correctness or the reliability of statistical data used in the study, although these aspects are not omitted due to the Reviewer's neglect. By verifying the results, we want to establish without doubt that the Author is not presenting only the findings that support the hypothesis, while ignoring those areas of solutions where the analytical instruments failed. So, what are the hindrances to prepare a complete evaluation, which is not confined to test results, but also addresses the research process which has to be effective? Is it possible to provide a complete analysis of the issue in a paper of such a limited content? The answer is "no", but it is worth making an attempt and analysing the relevant relation between the quality of empirical data used in the course of the research process and the results.

Research processes based on empirical data are reviewed with a belief that reliable data have been used by the investigator. Nevertheless, a belief cannot be a basis for judging the research work quality. Hence, the question about reliability of statistical data used for tests and analyses remains open.

A cognitive bias, taking its source in intuition, is another reason for invalid evaluation of a research process[1]. Cognitive errors result from an insufficient statistical data sense [Kahneman i Tversky, 1974]. This problem concerns those processes, where results are obtained based on small statistical samples. In such cases, scientific conclusions are usually distorted, since we are inclined to accept results of tests without sufficient information required to make generalizations and draw conclusions.

When writing scientific reviews, we are often impressed by the structural correctness of the paper. We value highly an introduction to the scientific problem offered to the reader, the contents of scientific hypotheses, the accuracy of empirical data selection used by the author when verifying the hypotheses and by the logic of conclusions drawn from the test results. Our judgements are usually built from a perspective, where problem perception is singled out, while addressing such aspects as intellectual efficiency of the scientific hypothesis formulation, selection of analytical methods, interpretation of results and scientific conclusions. Yet, the problem of statistical data reliability may escape evalua-

[1] The notion of biases was introduced by Kahneman, who argued that under certain circumstances, these can be expected. For example, when attending a lecture, where the lecturer presents scientific hypotheses along with a reasoning intended to prove these, manifesting a high degree of self-confidence, the audience will appreciate the presentation better than it deserves.

tion. Statistical intuition may confuse the reviewer, who, impressed by the sometimes perfect structure and contents of the paper, reviewer loses the process of preparing empirical data. When sensitizing the reviewer's mistrust towards this part of the process to a maximum degree, one should have doubts regarding the source of information, especially in case of confident data – this happens sometimes, when the author has gained access to such a data base by ways known only to himself or herself. Besides, examples of making up for deficiency of data or simply producing false data can also give rise to concerns.

In the history of the last decades, spectacular cases of data forgery were recorded. In the period between 09 and 19 September 1992, Wayne James Nelson, a chief accountant and manager in the office of the Arizona State Treasurer cashed 23 checks. The fraud was detected, although most of the amounts were below USD 100,000 – for such operations no additional control, authorization or countersigning was required.

It was Mark Nigrini who brought to the attention the probability of false financial data fabrication at Enron, a California-based energy company. Analysts had no idea, where the corporation's profits came from and still, this did not prevent them from recommending its shares to investors. There would have been no Enron scandal, if the company did not use off-balance-sheet, special purpose vehicles to conceal huge losses of the company [Nigrini, 1999][2].

In June 2009, the Iranian government arranged a re-count of the presidential election votes in response to claims of ballot fraud to have occurred in the three largest electoral districts. Boudewijn F. Roukema from University of Mikołaj Kopernik in Torun analysed the distribution of the number of votes, identifying significant anomalies in the election results distribution.

What statistical instruments were used when revealing the fraudulent actions of the Arizona State Treasurer office manager, challenging the reliability of Enron's financial statements or the results of the presidential election in Iran?

1. Instruments for verifying statistical data reliability

In 1881, Simon Newcomb published a hypothesis that "the law of probability of the occurrence of numbers is such that all mantissa of their logarithms are equally probable", which was next formulated in 1938 by Frank Benford as

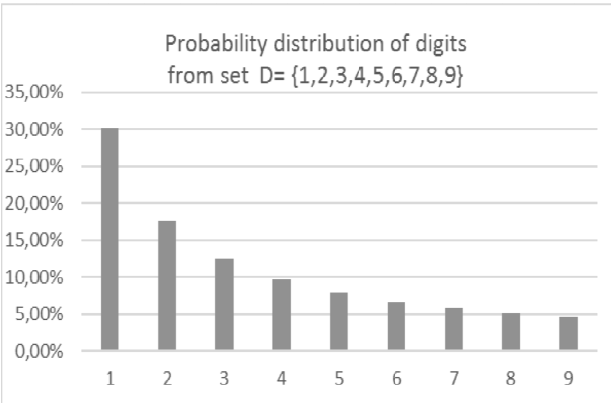
[2] Nigrini referred only to the fact that the frequency distribution of the first digits in Enron's financial reports did not follow Benford's law. Following this publication, company financial statements were re-audited.

a theorem that the frequency of digits from set $D = \{1, 2, 3, 4, 5, 6, 7, 8, 9\}$ occurrence on the first position in data follows distribution:

$$P(\mathit{first\ digit} = d) = \log\left(1 + \frac{1}{d}\right),\ d \in D. \tag{1}$$

When in 1995 Benford's hypothesis was proved by Theodore P. Hill, it became obvious that intuition was replaced by a validated statistical tool for analysing data [Newcomb, 1881, p. 39-40; Benford, 1938, p. 551-572; Hill, 1995, p. 354-363].

A discrete distribution of the first digit probability in statistical data according to Benford is presented in Figure 1.



First digit	Frequency
1	30,10%
2	17,61%
3	12,49%
4	9,69%
5	7,92%
6	6,69%
7	5,80%
8	5,12%
9	4,58%

Fig. 1. First digit distribution in data according to Benford's law

Source: Based on: Benford [1938, p. 551-572].

The analysis of statistical data reliability can be expanded to cover the probability of the first n digits occurrence in a decimal notation of statistical data:

$$P_k^{(n)} = \sum_{i=10^{n-2}}^{10^{n-1}-1} \log\left(1 + \frac{1}{10i + k}\right),\quad k \in \{0,1,2,3,4,5,6,7,8,9\} \tag{2}$$

In case when $n \geq 2$, the probability distribution of an event of the first n significant digits occurrence transforms into uniform distribution ($P_k^{(n)} \to 0,1$, if only n is high enough):

$$\exists_{0 \le k \le 9} \lim_{n\to+\infty} P_k^{(n)} \Leftrightarrow \lim_{n\to+\infty}\left(\log\left(\frac{\Gamma\left(\frac{1}{10}(k+10^n+1)\right)}{\Gamma\left(\frac{k+1}{10}+10^{n-2}\right)}\right) - \log\left(\frac{\Gamma\left(\frac{1}{10}(k+10^n)\right)}{\Gamma\left(\frac{k}{10}+10^{n-2}\right)}\right)\right)$$

where:

$\Gamma -$ gamma function, has been estimated using the Wolfram alpha package.

My curiosity, which has come close to obsession, turned my interest towards students' master's theses I was reviewing or supervising. I chose the theses whose authors were using the available statistical data bases. I verified a reliability of these data and my observations made me reflect on the rules of writing scientific reviews. When checking the statistical data sources referred to in the theses I did not find any misrepresentation of source data in students' papers. The reviewer's concern arises around those papers, whose authors plead a data sources confidentiality clause and do not quote them in their papers. So far, I used to trust authors in such cases, believing that the results, and consequently – the interpretations were based on the source data referred to, but unavailable.

Aside from the cases of deliberate misrepresentation of statistical data used as a basis for analyses, one should answer a crucial question, whether people, and scientists in particular, are defenceless against fraudulent representation of data? Doubts are based on suppositions and the situation is far from being comfortable, since the work occurs in an atmosphere of mistrust in such an important element of the research process as statistical data. In order to reduce the consequences of risk associated with disbelief in data reliability, one needs to expand the scope of work, designing efficient instruments which enable verification of data reliability, or alternatively, a choice of such instruments that have already been approved by the scientific circles as valid.

Statistical data can be obtained as a result a transformation of source data, but if the author of the study fails to indicate this, any review of the scientific process is worthless, the reviewer remaining – regrettably – unaware of the fact. A case, when the source of data is trustworthy, but the rule used for of transformation is unknown, does not differ from the case described in the previous sentence. Then, a question whether the transformed data set retains properties of the sets from which it is being defined, is becoming a matter of relevance to the process of scientific process. An answer was given by an American mathematician, Hill Preston Theodore. Namely:

– data sets still follow the Benford's law, if all data set elements are multiplied by a constant value,
– transformation of set elements presented in a decimal system notation into any other notation system does not result in a loss of the source set properties,
– mathematical operations (addition, subtraction, multiplication, division, exponentiation) do not cause the transformed data set to lose Benford's properties [Hill, 1995, s. 357].

The properties of sets defined by Hill P. Theodore are of high relevance to verification of data reliability in those cases, when data have been obtained through transformation. Hence, to evaluate data quality it is enough to verify the reliability of source data and to identify the transformation formula.

The phenomenon of Benford's law, although little known in the scientific circles, deserves more interest, since it enables verification of statistical data reliability. The propriety of this instrument is of high relevance to the scientific process review in the part which is beyond the researcher's influence, since if scientific conclusions are reached as a result of data transformation, the researcher would like to know the "quality" of data.

2. Instruments for testing the goodness-of-fit between empirical distribution and Benford's law

To answer, whether the first digits frequency probability distribution in statistical data sets follows the Benford's law, one does not need to design any new verification tools. To verify hypothesis H_0:

$$H_0 : \{ \textit{empirical distribution is consistent with the Benford's Law} \\ \vee \\ H_1 : \{ \textit{empirical distribution isn't consistent with the Benford's Law} \tag{3}$$

one may use the chi-square test. This is a classic instrument used in testing procedures, when solving the problem of goodness of fit, but its imperfection reveals itself when small statistical samples are dealt with. In such cases, the Kolmogorov-Smirnov test or Kuiper's test is of greater "statistical power".

As an alternative tool for the verification the goodness of fit of the first digits occurrence probability distribution to Benford's law, regression analysis can be used. The goodness of fit is tested by relevance analysis of structural parameters for the relation between the frequency of *i-th* digit occurrence on the first position of data being analysed and the *i-th* digit frequency on the first position estimated by the Benford's law:

$$Y_i = \alpha_0 + \alpha_1 X_i + \xi_i,\ i \in \{1,2,3,4,5,6,7,8,9\} \tag{4}$$

Y_i – the frequency of the *i-th* digit occurrence on the first position of data being analysed,

X_i – the frequency of the *i-th* digit occurrence on the first position estimated by Benford's law,

ξ_i – random component[3].

[3] $E(\xi_i) = 0$,constant and finite value of the random component variances, $\forall i \neq j$, ($i = 1,2,3,\dots,9$), $\text{cov}(\xi_i, \xi_j) = 0$. Covariances equalling null indicate the perfect fit of distributions, $\alpha_0 = 0$, $\alpha_1 = 1$.

The distribution's goodness of fit is verified by the result of an acceptance the null hypothesis, which by definition takes a stand on relevance of the relation's structural parameters evaluation (4):

$$\begin{aligned} &H_0 : \{\alpha_0 = 0 \quad \wedge \quad \alpha_1 \neq 1, \\ &\vee \\ &H_1 : \{\alpha_0 \neq 0 \quad \vee \quad \alpha_1 = 0. \end{aligned} \tag{5}$$

The accepting of the hypothesis H_0 means that the empirical distribution follows the Benford's law.

3. Credibility of financial data of chosen subjects Polish capital market

The success, well-known the explorers' narrow group, instrument of verification of credibility statistical data, it induces to undertaking of test of analysis of data financial participants Polish capital market. In this part of study on basis at random accomplished choice, the financial data be presented 5 the companies the Polish GPW and their credibility in consequence with aim of paper was verified peaceably using to this the schedule the Benforda. The choice of companies to investigation, he restrained to these subjects which withdrew the public quotation of value of action. Among year 2004 and 2009 all studied subjects resigned from GPW at last.

3.1. Statistical data characteristics

I do not intend to create an aura of a scandal which would imply questioning the reliability of statistical data in the available data bases. The researcher's curiosity turned my interest towards unrestricted access data bases, namely – financial statements of the Warsaw Stock Exchange companies.

The choice of data base was not incidental – as of 5 February 2013, 438 companies were listed on the WSE. I did not intend testing the fit of financial data distribution for all of the WSE companies, therefore a selection criterion had to be determined. Within the last several years, 16 companies withdrew from the stock exchange, hence accepting the "withdrawal" as a criterion – without any speculations about the reasons behind the "withdrawal" – seemed to be a natural thing to do[4].

[4] As of 6 April 2011, the group of companies that withdrew from the stock Exchange included: ABG, Bankier.pl, Europejski Fundusz Leasingowy, Exbud, Green Technology, Huta Szkła Gospodarczego „Irena", Icopol, Interia.pl, Praterm, Prokom Software, Stomil Olsztyn, Swarzędzkie Fabryki Mebli, Uniwersal S.A., E. Wedel, Wika Polska, Wydawnictwa Szkolne i Pedagogiczne. Dates of withdrawal vary, all of them remaining within the period [2003-2009].

The Benford's law „power" was verified through an analysis of 5 companies: ABG, Europejski Fundusz Leasingowy (EFL, European Lease Fund), Huta Szkła Gospodarczego IRENA (IRENA Glassworks), Stomil Olsztyn and PROKOM.

In case of ABG, EFL and Stomil Olsztyn, sales performance data are available for the period until QIV 2003 – 24 facts. IRENA Glassworks reports cover the years 1998-2009, 48 facts, while for PROKOM, 40 facts of the years 1998--2007 are available.

Table 1. The finance results companies

		ABG	EFL	IRENA	STOMIL OL	PROKOM
1		2	3	4	5	6
I qu.	1998	12 138	114 207	17 347	196 613	45 243
II qu.		12 035	141 550	20 193	214 695	42 753
III qu.		17 233	135 423	20 838	249 187	106 592
IV qu.		100 523	184 710	19 957	222 764	123 379
I qu.	1999	20 140	154 056	16 696	206 948	127 778
II qu.		30 961	186 601	17 389	239 067	149 567
III qu.		38 673	203 989	21 058	273 929	175 114
IV qu.		51 018	248 780	21 624	272 652	178 733
I qu.	2000	33 413	216 014	20 108	285 725	185 298
II qu.		34 032	242 848	22 659	316 105	165 371
III qu.		27 620	248 658	24 751	175 594	247 043
IV qu.		106 016	285 028	21 980	265 581	229 679
I qu.	2001	30 841	254 355	20 789	312 267	212 051
II qu.		44 663	276 498	18 931	263 642	171 555
III qu.		27 155	293 048	22 997	141 037	159 175
IV qu.		144 567	334 929	15 986	290 225	298 296
I qu.	2002	67 746	94 002	16 777	317 283	182 293
II qu.		61 948	86 455	21 895	332 917	192 466
III qu.		58 195	90 586	22 809	342 030	213 672
IV qu.		134 600	85 609	17 324	315 526	331 099
I qu.	2003	115 736	89 303	21 040	390 582	218 022
II qu.		55 919	95 306	19 565	375 292	220 061
III qu.		46 691	97 949	22 478	397 013	193 982
IV qu.		87 226	113 219	19 715	387 155	241 676
I qu.	2004	45 999		22 524		181 975
II qu.		76 486		23 510		183 689
III qu.		0		22 804		163 541
IV qu.		46 214		20 268		246 198
I qu.	2005	58 555		16 639		111 907
II qu.		19 723		17 885		171 450
III qu.		0		20 388		263 098
IV qu.		120 118		17 556		228 952

Table 1 cont.

1		2	3	4	5	6
I qu.	2006	35 297		16 783		130 452
II qu.		101 665		14 711		148 074
III qu.		52 034		15 088		126 183
IV qu.		60 676		16 070		149 110
I qu.	2007	38 299		15 983		134 738
II qu.		73 370		14 325		116 537
III qu.		110 589		15 157		144 512
IV qu.		141 510		15 832		120 547
I qu.	2008			16 952		
II qu.				16 025		
III qu.				14 038		
IV qu.				8 730		
I qu.	2009			8 517		
II qu.				9 731		
III qu.				9 475		
IV qu.				12 648		

Source: [www 1].

The statistical sample size is an important factor as regards selection of tools for testing the goodness of fit between the probability of the statistical data first digits and Benford's law, since in case of small samples, the statistical "power" of the chi-square test is insufficient for a conclusive verification of the goodness of fit.

3.2. Test results

Table 2. Estimations of the regression function (4) for companies withdrawn from the Warsaw Stock Exchange. Estimated chi-square statistics. Results of verification of hypotheses (3), (5)

No	Company	α_0	α_1	$\lvert t(\alpha_0)\rvert$	$\lvert t(\alpha_1)\rvert$	Take H_0 $t_{kr}=2.365$	χ^2	Take H_0 χ^2_{kr} 15.51
1	ABG	-0,0999 (0,0283)	1.8995 (0,2080)	3,532	9,101	H_1	12,01	H_0
2	EFL	0,0004 (0,000)	0,9962 (0,4821)	0,0064	2,066	H_1	17.58	H_1
3	IRENA Glassworks	0,1069 (0,0242)	0,0375 (0,1782)	4,427	0,2107	H_1	26,45	H_1
4	Stomil Olsztyn	0,0328 (0,0323)	0.7052 (0,2382)	1,014	2,961	H_0	6,61	H_0
5	PROKOM	0,0720 (0.0327)	0,3520 (0,2416)	2,198	1,457	H_1	14,08	H_0

The verification result does not settle the issue and any speculations about the causes of companies withdrawal from the WSE should be avoided[5]. Out of the group of five companies, in three cases – ABG, EFL, IRENA Glassworks – the financial data distributions of the period of these entities' presence on the WSE do not follow the Benford's law.

Here, both in the relevance verification of the structural parameters of relations between the financial data first digits frequency distribution and the theoretical distribution, i.e. Benford's law, as well as in the goodness-of-fit chi-square test outcomes, the results show a clear lack of fit. Only in case (Stomil Olsztyn), the verification does not provide a basis for rejecting hypothesis that the companies' financial data distributions followed Benfor's law. According to the suggestion given in the conclusion of the paper, an in-depth analysis is recommended here, which means a complete audit procedure covering not only financial issues, but also the area of legal solutions and decisions, tax decisions, IT system assumptions and operation, as well as the HR management policy guidelines and implementation.

Conclusions

The present paper has been structured to reflect my intended purpose. The main objective was to draw the scientific circles' attention to the need to refine the standards of writing scientific reviews. At the same time, this objective provided an opportunity to supplement of argument the pretext about verification of investigative hypothesis formulated in the abstract.

The goodness-of-fit between the empirical series first digit probability distribution and the theoretical distribution – Benford's law – was tested using two instruments: the chi-square test to verify the hypothesis of both distributions fit and the linear regression model, to mapp the relation between the frequency measure of the empirical and theoretical distribution of the statistical data first digit.

The part third attached herewith contains assumptions for an empirical research, as well as the research results. In this section, criteria for statistical data

[5] The results presented by W. Zając in the announcement "Data verification process" published on BENFORD.PL are definitely negative for 17 American companies covered by the analysis. In the period between 1 July 1998 – 30 June 2003, these companies' stocks were suspended or withdrawn from the New York Stock Exchange. The companies were suspected of accounting frauds.

base selection are specified. The analysis covers companies withdrawn from "the floor" in the years 2003-2009 and companies still present in the public offer[6].

Here, a question arises, whether the results have satisfied the author's expectations and most importantly – whether they appear convincing to the reader. It is impossible to make a clear-cut statement that the grounds for withdrawal of a company from the public offer were of an informal or non-economic nature.

The conclusive verification of the hypothesis requires a financial audit to be conducted. The analytical tool used for the task informs of the lack of fit, but it does not indicate the sources of the discrepancy between the first digit frequency in the analysed time series data and the Benford's law.

The intended purpose of the test was to work out a concept of a standard for source data analysis. A reviewer wishing to evaluate the correctness of an experiment should be aware its deficiencies in case if the possibility to verify the reliability of data is denied. Being uncertain about the statistical data quality, the reviewer may find it difficult to determine, whether the experiments described in the publication have really been conducted and it or such results what were got was presented in this paper.

In 2010, Elsevier, a company publishing scientific literature, proposed an interesting solution, the purpose of which was to establish a system supporting the reviewers' work. The idea behind the system would be to enable efficient communication between the reviewer and the author. The scenario assumed a data sharing option, an access to the software used in tests and analyses, detailed descriptions of experiments and their results. In particular, the solution should be:

- executable – the reviewers should be able to work interactively with tables, graphs, etc. published in papers,
- compatible – the system should be flexible enough to allow using the available software and system environment,
- capable of being validated – e.g. offering the possibility of automated statistical processing of the results,
- subject to copyright – important in the age of common access to data and scientific results,
- capacious – so as to enable sharing a great number of data sets,

[6] There is a certain underlying meaning behind the selection criterion, intended to justify possible suspicions of deliberate withdrawal from "the floor". The American experience shows that companies used to withdraw from participation in the public offering out of fear that misrepresentation of financial data might be discovered. Consequences of this choice were expected to verify a hypothesis which has not been verbalized in the paper, that publicly listed companies publish financial statements that follow the Benford's law.

- subject to access control – so as to enable tracking the processes being underway,
- protected against plagiarism, viruses and code contamination[7].

The process of scientific review generates excitement of both authors of papers under review and reviewers as well. In my opinion, developing evaluation standards is an objective, which, when achieved, will pave the way for the open science practices. The standards referred above correspond with this concept – namely, they call for a scientific data and research notation enabling their re-use by other scientists. Furthermore, they advocate change of the legal licence, if this would provide access to research materials. Some of the scientific circles pursue the open science idea even further, adding another postulate, namely – development of a special language which would facilitate integration of the research results achieved in the past.

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[7] Elsevier is a renowned international publishing company, publishing scientific, medical and technical literature. On the Executable Elsevier Paper site the company announced a contest inviting proposals of a system supporting the work of the scientific journal reviewers. The purpose of the Elsevier Executable Paper Grand Challenge is to provide monitoring of the way how scientific information is used and processed; New York, December 2010.

PROBLEM OCENY PROCESÓW BADAWCZYCH – WERYFIKACJA WIARYGODNOŚCI DANYCH STATYSTYCZNYCH

Streszczenie: Tematem niniejszego artykułu jest zagadnienie oceny prac badawczych, a w szczególności ocena wiarygodności danych statystycznych użytych w badaniu. Pomijam fakt, kiedy Autor pracy nie podaje źródła danych, co dyskwalifikuje badanie. Zdarzają się przypadki, gdy Autor powołuje się na konieczność utajnienia źródła danych, wówczas Recenzentowi pozostaje wybór: uznać, że dane są wiarygodne bądź odrzucić to założenie, a tym samym odstąpić od wykonania recenzji. Jak wyeliminować istotny mankament recenzji? Odpowiedzi może dostarczyć następująca hipoteza: *Jeśli dane statystyczne mają rozkład zgodny z rozkładem Benforda, to z prawdopodobieństwem graniczącym z pewnością można zweryfikować wiarygodność danych wykorzystanych w badaniu.* W zakończeniu artykułu sformułowano założenia systemu wspomagającego Recenzentów przy formułowaniu ocen prac badawczych. W załączniku zamieszczono wyniki badania empirycznego, które z założenia mają wesprzeć proces weryfikacji sformułowanej hipotezy badawczej.

Słowa kluczowe: wiarygodność danych empirycznych, rozkład Benforda częstości wystepowania pierwszej cyfry danych statystycznych.