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Statistical formats to optimize evidence-based decision making: A behavioral approach

Iván Arribas [a,*], Irene Comeig [b], Amparo Urbano [b], José Vila [b]

[a] University of Valencia, ERI-CES, Ivie, Spain
[b] University of Valencia, ERI-CES, Spain

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ABSTRACT

Statistical information is crucial for managerial decision making. The decision-making literature in psychology and mathematical cognition documents how different statistical formats can facilitate certain types of decisions. The present analysis is the first of its kind to assess the impact of statistical formats in the presentation of data from market research on both the optimality of market decisions and the time required to perform the decision-making process. An economic experiment provides the data for this study. The experiment presents statistical information in *simple frequencies* and *relative frequencies* using *numerical* and *pictorial* representations in the context of different informational environments. The key findings are that statistical information presented in terms of relative frequency formats gives rise to more accurate decision making than data presented in terms of simple frequencies, independently of the informational environments. When time is the relevant variable, numerical formats lead to a faster interpretation than pictorial ones. Since the number of factors defining the four statistical formats and the different informational environments is quite large, an orthogonal design offers a suitable experimental design. This design keeps the experiment manageable without substantially reducing its analytical power.

1. Introduction

Statistical information is crucial for decision making. Several studies discuss how people have difficulty interpreting probabilistic information (e.g., Gigerenzer & Edwards, 2003; Osman & Shanks, 2005). While difficulties with probabilities sometimes seem to result from a lack of experience or education, social scientists argue that the problem lies in the presentation of information (Gigerenzer & Edwards, 2003). Specifically, previous research in psychology shows that different statistical formats can facilitate some types of decisions. Regarding Bayesian reasoning, Gigerenzer and Hoffrage (1995, 1999), and Hoffrage, Lindsey, Hertwig, and Gigerenzer (2000) reveal that presenting the statistical information as simple frequencies (e.g., 1 out of 10 visits to an e-commerce website leads to an actual purchase), rather than as single-event probabilities (e.g., the probability that a visit to an e-commerce website leads to an actual purchase is 0.1), can improve people's decisions. These authors argue that the facilitation of natural frequencies comes from: i) reducing the computations needed to solve the problem; and ii) fitting better with the ways in which humans have experienced statistical information over history (see also Brase, 2007). Ghosh and Ghosh (2005) review several applied studies that indicate how medical students and practitioners have difficulty explaining, interpreting or calculating probability statistics specific to medicine. Changing the format of the probability information has a significant impact on the subsequent use of this information.

Research in mathematical cognition about how people process numerical quantities also supports the facilitation of presentations in terms of frequencies, and therefore of whole numbers, rather than in terms of rates (i.e., x/y, as fractions or proportions) (see Butterworth, 2007; Ni & Zhou, 2005).

Another related question is the role of statistical-processing biases and their role in decision making. For instance, Soyer and Hogarth (2010) conduct a survey to 257 academics designed to test the ability of economists to make probabilistic predictions from regression outcomes presented in a manner similar to those published in leading economic journals. Many respondents underestimate uncertainty by failing to take into account the standard deviation on the estimated residuals. The addition of graphs fails to substantially improve inferences.

The important questions about how good or accurate people are at making judgments and what these judgments depend on provoke considerable controversy in the psychological literature. The psychological research on judgments under uncertainty typically asks subjects to solve a statistical problem and compares decisions between two choices with different wordings. However, as Girotto and Gonzalez (2007) point out, standard word problems are not the best instruments to test general hypotheses about the nature of human judgment (Macchi, 2000; Macchi & Bagassi, 2007; Macchi & Mosconi, 1998).

* Corresponding author at: Department of Economic Analysis, University of Valencia, Avenida Tarongers, s/n, Valencia, 46022, Spain. Tel.: +34 961 625 351; fax: +34 963 828 249.

E-mail addresses: ivan.arribas@uv.es (I. Arribas), irene.comeig@uv.es (I. Comeig), amparo.urbano@uv.es (A. Urbano), jose.e.vila@uv.es (J. Vila).

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Brase (2002) simply and directly evaluates whether—apart from simplifying statistical inference tasks—simple frequencies defined on small reference groups are clearer than other formats. The author reveals that, after eliminating possible confusion for subjects in the calculations, subjects perceive more clearly simple frequencies (based on small reference groups, e.g., 1 out of 5) and to some extent relative frequencies (percentages, e.g., 40%) than absolute frequencies (e.g., 90 million Americans) and single-event probabilities (e.g., 0.33).

Motivated by the work of Brase (2002), this study goes a step further and asks: which statistical data performs better in decision making—10 out of 100 (simple frequencies), or 10% (relative frequencies)—and under which representation—numerical or pictorial? To answer this question an economic experiment provides data to compare simple and relative frequency formats, each of them under numerical and pictorial representation. No existing experiment attempts to investigate the communication of statistical market information in business reporting. Therefore, this is the first paper to present an economic experiment on the way that statistical representation of frequencies facilitates decision making.

Three features of the experiment are worth of highlighting. First, the experiment is an economic experiment, which means that experimental subjects receive a payment, depending on their performance, to establish suitable behavioral incentives. Second, the present analysis assesses the impact of different statistical formats in the presentation of data from market research (framed in several informational environments) on the accuracy of market decisions. Thus, the analysis deals with a problem of managerial decision making, where the experimental subjects are students enrolled in several academic degrees related to business administration. The methodology is that of typical decision-making tasks, namely choices between alternatives. Both simple frequencies and relative frequencies appear as numerical and pictorial representations. These statistical formats appear in the context of several informational environments, namely sample size, number/percentage of buyers in the sample and supply costs in the different versions of the managerial problem. Further assumptions are that two sample sizes exist (two different numbers/percentages of buyers) and that the market has asymmetric costs (either over-supplying costs or under-supplying costs). Moreover, the choices present three levels of difficulty. The impact of each statistical format in decision making undergoes quantification in terms of both the time required to make decisions and the accuracy of these decisions. Third, in this experiment, the number of factors to consider, namely the statistical formats and the different informational environments, is quite large. Specifically, five factors receive attention (statistical formats, sample size, number/percentage of buyers, costs and responses). Three of these factors have two levels, one factor has three levels and the remaining factor has four levels. The possible combinations of these factors define 96 different choices for the subjects. Such a high number of decisions might overwhelm subjects or require several sessions with different subjects. An orthogonal design whereby the number of alternatives reduces to 25 (a quarter of the total number) helps resolve this problem, thus allowing the experiment to run in just one session and with the same pool of subjects. The methodology of orthogonal design allows for a reduction in the number of decisions without substantially lowering the capacity for analysis (mainly related to the interaction order between factors). Thus, this approach also offers a contribution to the experimental design methodology.

The key findings of the paper are the following. (1) Statistical information presented in terms of relative frequency formats (i.e., percentage of buyers) gives rise to better decision making than information in terms of simple frequencies (i.e., the total number of buyers) independently of the informational environments. (2) Numerical formats are better than pictorial frequency formats. Therefore numerical relative frequency formats perform best for decision making. (3) The time required for decision making is lower under numerical formats than under pictorial ones. (4) Under pictorial statistical formats, relative frequencies perform faster than simple frequencies. (5) The sample size matters, and the lower the sample size, the lower the time needed to make decisions. Nevertheless, because the sample sizes are 100 and 500, the normalization of 100 may also drive the result as well as the smaller quantity. (6) None of the interactions between an informational environmental factor and the statistical format factor significantly affects either the accuracy or the time to make decisions. The outperforming of the numerical relative frequency format may lie in its ability to provide an appropriate set structure of the problem by reducing computational demands. Finally, the paper develops the managerial implications of these findings and establishes good practices to present statistical market information in business reporting.

2. Experimental design

An economic experiment provides an appropriate tool to examine which type of frequency (simple or relative) and which type of representation (numerical or pictorial) give more accurate and fast responses to managerial decision making. The experiment presents the following managerial decision-making environment. Subjects receive the results of a simple market research exercise and must choose one out of two alternative provision levels (number of units) of a good to be allocated in a market. The market research provides information on the percentage of the customers in the sample that will buy a unit of the good (only one unit per customer) under the assumption that the survey is completely reliable (a customer will buy a unit of this product if and only if she or he demonstrates her or his intention to buy during the survey). This information is displayed using four statistical formats (Fig. 1).

Providing information with these four types of presentations avoids possible word confusions among the four statistical formats. Moreover, the cost of an unsold product unit (over-supply cost) and the cost of leaving a subject without the product (under-supply cost) are different. Subjects choose between two possible answers in each round. These two possible answers can be of three types: i) Correct and Focal; ii) Correct and Opposite; and iii) Correct and Extreme. *Correct* means the right answer to the decision problem, namely that the number of units of the product to allocate to the market to maximize expected profit given the sample information, the market size and the asymmetry of supply costs. *Focal* refers to the option of allocating to the market a number of units proportional to the number of clients that will buy the product in the sample, with no other consideration on the asymmetry of over-supply and under-supply costs (i.e., given a market size of 1000 potential buyers, if 30% of clients in the sample buy the product, the number of units to allocate to the total market will be 300, no matter if the over-supply cost is larger or smaller than the under-supply cost). The answer *Opposite* refers to an answer that is smaller than the focal one, in those cases where the right answer is larger than the focal answer and vice versa. The final option is *Extreme*, whereby the number of units allocated to the market is larger than the right number in those cases where the right answer is also larger than the focal answer. The converse is also true, namely that a choice is extreme when the choice is lower than the right answer and the right answer is also smaller than the focal option.

The experiment considers two cost treatments (higher over-provisioning cost and higher under-provisioning cost). Each treatment includes two sample sizes (500 and 100) as well as two different proportions of elicited buyers in the sample (30% and 70%).

As previously mentioned, subjects had to deal with 96 possible decision-making problems (cards). The use of an orthogonal design reduced the number of cards to 25 (a quarter of the total). From the medical literature the experiment borrows the methodology of orthogonal designs, which is novel in the design of economic experiments. Such a design keeps the experiment manageable without substantially reducing its analytical power. Specifically, such a design enables the inclusion of multiple factors in an experiment because the sample size remains small, thus making the estimation of both the main effects and all the