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Extracting business information from graphs: An eye tracking experiment☆

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ABSTRACT

Information graphics are visualizations that convey information about data trends and distributions. Data visualization and the application of graphs is increasingly important in business decision making, for instance, in big data analysis. However, relatively little information exists about how people extract information from graphs and how the framing of the graphic design defines may 'nudge' and bias decision making. As a contribution to fill this gap, this study applies the methodology of experimental economics to the analysis of graph reading and processing to extract underlying information. Specifically, the study presents the results of an experiment whose baseline treatment includes graphical and numerical information. The authors analyze how the information extraction changes in other treatments after removing the numerical information. The experiment applies eye-tracking technology to uncover subtle cognitive processing stages that are otherwise difficult to observe in visualization evaluation studies. The conclusions of the study establish patterns in the process of graph analysis to optimize data visualization for business and policy decision making.

1. Introduction

Data visualization commonly helps to inform data users in a wide range of thematic areas, from health behavior to traffic accidents. Specifically, data visualization and the application of graphs are increasingly important in business decision making, policy making, and scientific research. Despite of the importance and almost universal application of data graphs and statistical charts, relatively little information exists on how people actually extract the information from graphical representations and how the framing of the graphic design defines may bias decision making and persuade users to a specific decision (Feeney, Hola, Liversedge, Findlay, & Metcalf, 2000; Lewandowsky & Spence, 1989). As a contribution to fill this gap, this study presents the results of an eye-tracking economic experiment to analyze how human beings actually scan and process statistical graphs to extract their underlying information. The application of the economic experimental methodology, including economic incentives for a successful completion of tasks, increases the validity of the results in comparison to the results from surveys or psychological experiments (Hernandez & Vila, 2014; Holt & Laury, 2002).

The study helps to answer a twofold research question. From a descriptive viewpoint, the study provides experiment-based insights on how real people look at a statistical chart and which are the pieces of information that they actually process and integrate in their decision-making process. The research also studies how different visualization patterns lead to more or less convenient decisions. From a *normative* viewpoint, this research provides guidelines to facilitate a more effective analysis of basic statistical charts. Answering these descriptive and normative questions has not only a scientific interest—the enhancement of the understanding of the cognitive processes founding active reading of statistical charts—but also a clear managerial implication, providing with an experimental sound contribution on how to improve statistical charts to lead to better decision making in business and policy.

2. Theoretical framework

The descriptive and normative research questions in the introduction are not new. Starting from the seminal work of Buswell (1935), this literature is exponentially growing during the last years with the quick development of big data methods and visualization software (Shixia, Weiwei, Yingcai, & Mengchen, 2014). However, most of these studies follow a computer science approach (Diehl, Beck, & Burch, 2010; Wang, Chou, Su, & Tsai, 2007) and do not focus on providing and analyzing empirical evidence on the underlying cognitive procedures or the effectiveness of alternative visualization frames for a proper understanding of the information in a graph.

The literature presents two experimental approaches to deal with these research questions. The first one is the 'black box' approach.

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Under this approach, experimental subjects receive the same information in different visualization frames. Then, these studies measure and compare a series of indicators of the quality of the decision making (accuracy of the answer to a question, time required to make the decision, etc.) among different frames. Although most studies apply psychological experiments, where subjects do not receive economic incentives, Arribas, Comeig, Urbano, and Vila (2014) provide an interesting example of the application of an incentivized economic experiment. They present statistical information using numerical and graphical representations and assess the impact of such statistical formats on both the optimality of market decisions and the time required to complete decision making. Although the 'black box' approach allows for analyzing the effectiveness of alternative visualization frames, this approach does not provide information on subjects' scanning patterns: order, number of times, and during how long subjects actually look at each specific element of the statistical chart, etc. A good understanding of the underlying cognitive processes and the establishment of evidence-based normative guidelines to improve data visualization requires this type of information and the consideration of alternative approaches.

A proposal for this alternative is data collection using eye-tracking tools, which are able to provide real-time information on where a subject is locating her or his eyes and allows for the identification of actual visualization patterns. Eye movements may seem very stochastic but are indicators of higher-level cognitive processes (Conati & Maclaren, 2008). An eye-tracking methodology helps uncover subtle cognitive processing stages that are otherwise difficult to observe in visualization evaluation studies. Although completion time and accuracy on specific tasks may indicate that differences or problems exist, a deeper understanding of visual scanning strategies on information graphics may help to determine specific guidelines for designing graphs and selecting graph types for particular datasets and tasks. An eye-tracking methodology can help to observe these visual scanning strategies, providing richer information beyond that available from response time and accuracy-based methodologies (Goldberg & Helfman, 2011). However, the price for the information that sophisticated non-intrusive eye-trackers provide is the impossibility of running experiments with large samples able to support reliable statistical inference. For instance, sample size is 32 subjects in Goldberg and Helfman (2011) or 38 subjects in Burch, Heinrich, Konevtsova, Hoferlin, and Weiskopf (2011). This tradeoff between information accuracy and sample size is not a specific issue of eye trackin, but is a common feature of all neuro-economic experiments, where the complexity and time consumption in data collection usually limits data analysis to descriptive analysis, precluding the application of more sophisticated inference methods or statistical hypothesis testing.

The literature presents several examples of the application of eye-tracking methods to analyze graph-scanning strategies. For instance, Goldberg and Helfman (2011) present an illustrative eye-tracking study to compare how radial and linear graphs support value lookup tasks for both one and two data dimensions. This experiment presents linear and radial versions of bar, line, area, and scatter graphs to the participants, who complete each a counterbalanced series of tasks. Eye tracking also helps to classify error strategies and to support the establishment of improvement guidelines in the design of radial and linear graphs. As another example, Burch et al. (2011) apply eye tracking to identify visual exploration behaviors of participants solving a typical hierarchy exploration task by inspecting a static tree diagram. To uncover exploration strategies, they examine fixation points, duration, and saccades of participants' gaze trajectories. Huang (2013) highlights that graph esthetics usually come from common senses and personal intuitions—thus, their relevance to effectiveness is not clear—and conducts two eye-tracking studies in an attempt to understand the underlying mechanism of edge crossings. These studies show that eye tracking is an effective method for gaining insights into how people read graphs and how the esthetics conditions human graph-reading behavior.

However, the literature includes no previous examples in of the design and implementation of incentivized economic experiments with eye tracking: recording subjects' scanning strategy while they read basic statistical charts with information for a successful development of tasks with an economic incentive.

The present study is a first attempt to fill this gap and get together the potentiality of eye-tracking methods with the reliability of incentivized economic experiments. To this end, experimental subjects observe simple horizontal bar charts with the information on the percentage of purchasers of ten movies. Then, participants answer a simple multiple-choice question (the percentage of sales of the fourth most purchased movie) using this information. The task has an economic incentive and those subjects who answer the question properly receive 2 euros. Graphs present the information in two different frames, defining the two treatments of the experiment. Treatment 1 does not provide the numeric value of sales percentage and this information only appears on the ax of the chart. Treatment 2 shows this numerical value beside the bars, making the information in the horizontal ax redundant. During graph reading, a non-intrusive eye tracker records subjects' scanning strategy. This type of eye tracker provided more accurate information (precise recording of eye movement almost at a pixel level) and has lower impact on the subjects.

The structure of this study is as follows. This section summarizes the theoretical framework and Section 3 presents the economic experiment and the features of the eye tracker. Section 3 also describes the methodology used to analyze eye-tracking data, based on the definition of areas of interest and descriptive comparison of heat maps. Section 4 summarizes the results of the experiment and Section 5 presents a brief discussion of these results.

3. Method and experimental design

An eye-tracking economic experiment provides an appropriate tool for this study to examine the visualization patterns when reading simple statistical graphs. In the experiment, subjects receive information on the sales levels of ten movies through a bar graph that represents the percentage of participant in a previous experiment that actually purchased each movie. In a first step, subjects look at the graph during 15 s for a general exploration. After that, during 30 s and under the graph, the screen shows the question 'Which is the sale percentage of the fourth most sold movie?' with four multiple-choice answer options: 'From 16% to 25%', 'From 26% to 35%', 'From 36% to 45%', and 'From 46% to 55%'. Subjects receive and economic incentive of 2 euros if they answer the question properly. The experiment considers two treatments. In the first one, the bar chart does not include the numerical values of the sales percentage of each movie. Treatment 3 actually shows these values beside the top of each bar (Fig. 1). To avoid learning effects, the experimental design is between subjects, with half of the sample participating in each of the treatments.

The eye-tracker system Tobii T120 records eye fixation data. A processor located in a dedicated computer embedding the eye tracker calculates the gaze data. This eye-tracking system integrates a 17-in. TFT monitor, allowing for non-invasive data collection, because with this experiment, subjects need not wear special eye-tracking glasses that could make them feel uncomfortable and affect their behavior during the experiment. The eye-tracking device has a sampling rate of 120 registers per second and its precision values measured on human eyes are based on stimulus points on the native TFT screen (1280×1024 pixels). The interaction and analysis software Tobii Studio version 3.2.1 streams the data for further processing.

The experimental software-development environment includes the web technologies php and MySQL database. Tobii Studio allows to display webpages to participants simultaneously to the recording process. This software uses the website URL or a local address to open the site in Internet Explorer and automatically records all mouse clicks, key strokes, and webpages visited during the test.