Special Session Summary  How Do Consumers and Managers Process Numeric Information? the Role of Numerical Cognition

Manoj Thomas, New York University
Vicki Morwitz, New York University

[to cite]:

[url]:
http://www.acrwebsite.org/volumes/9118/volumes/v32/NA-32

[copyright notice]:
This work is copyrighted by The Association for Consumer Research. For permission to copy or use this work in whole or in part, please contact the Copyright Clearance Center at http://www.copyright.com/.
SESSION OVERVIEW

Consumers and managers frequently encounter numerical information. Managers often make decisions based on numerical information about historical trends of various decision variables. While making purchase decisions, consumers often encode and compare multi-digit prices and other product-related numeric information (e.g., attribute levels, quality ratings, etc.). Sometimes consumers evaluate a product-related number by comparing it to a comparison standard available to them from some context (e.g., at the point of purchase). On other occasions these comparisons are done vis-à-vis comparison standards recalled from memory. The complexity of numerical information and the fact that numerical information is used very frequently to make many important decisions makes numerical cognition a challenging and important domain for research. In this session we present research that draws from recent advances in cognitive psychology on numerical cognition. Specifically, we present three papers that examine how consumers and managers encode and process numerical information.

The first paper by Hutchinson, Alba and Eisenstein examines how managers process graphically presented numeric data. They find that the type of graphical format used to present numerical information affects the perceived relationship between numeric variables, and in turn, the decision heuristics used by the decision makers. Bar charts and cross sectional data encourage the use of informational heuristics (e.g., allocations similar to those that yielded the best results in data) and line charts and time-series data encourage the use of locational heuristics (e.g., compare year-to-year changes in allocation to year-to-year changes in outcomes). Further they find that these effects are large and are resistant to debiasing efforts.

The second paper by Thomas and Morwitz examines how consumers compare multi-digit decimal prices. For example, they examine whether consumers perceive the difference between $3.99 and $5.00 to be more similar to the difference between $4 and $5 or the difference between $3 and $5. Digital models of numerical comparison suggest that since numerical comparisons are made digit-by-digit, the difference between $3.99 and $5.00 should be perceived to be similar to that between $3 and $5. In contrast, holistic models of numerical comparison suggest that since numerical comparisons are based on the holistic magnitudes, the difference between $3.99 and $5.00 should be perceived to be similar to that between $4 and $5. Results from three experiments suggest that the range of the activated scale moderates the type of numerical processing used by consumers. Digital processing mode was found to dominate when the numbers were close to each other.

The third paper by Vanhuele et al draws on the triple encoding model of numerical cognition to examine factors that facilitate and inhibit consumers’ memory for prices. Their research focuses on the role of encoding processes in price recall accuracy. More specifically, they propose that prices are encoded in memory not only as analog magnitudes but also as auditory codes. Based on this premise they hypothesize that auditory features of prices will affect the accuracy of price recall. Results of three price knowledge surveys in France, the U.S. and Hungary provide evidence in favor of their hypotheses.

The three papers thus focus on the processes that underlie numerical inferences. Despite the ubiquitous nature of numerical information, relatively little work has been done this domain. This proposed session attempts to present some intriguing research questions and interesting empirical observations in this domain. The session will demonstrate the importance of integrating numerical cognition theories into research on consumer and managerial decision making, by demonstrating that they help explain the recalled accuracy and the perceived magnitude of numeric information, as well as the perceived relationship between numbers.


J. Wesley Hutchinson, University of Pennsylvania
Joseph W. Alba, University of Florida
Eric Eisenstein, Cornell University

Budget allocation is a primary responsibility for most managers. Moreover, allocation decisions are frequently supported by numerical data about past expenditures and their effects on sales and profits. Using these data requires inferences about causality that often depend on the correlational patterns that managers perceive in them. In earlier research (Hutchinson and Alba 1997), we demonstrated that the heuristics commonly used to make inferences from tables of numbers create strong biases in budget allocations, despite being reasonable approximations of normative correlation statistics. In particular, our paradigm revealed that decision variables with identical statistical properties can receive widely different levels of allocation, and these biases are systematically related to the heuristics that are used. In the present research, we use the same paradigm to show that similar heuristics are used for data presented in graphical formats, and they are similarly sensitive to the semantic frame of the data. In particular, we show that bar charts and cross-sectional data encourage the use of informational heuristics (e.g., allocations similar to those of that yielded the best results in data) and that line charts and time-series data encourage the use of locational heuristics (e.g., compare year-to-year changes in allocations to year-to-year changes in outcomes). We also show that these effects are large compared to the known effects of prior expectations, that they are very resistant to classic debiasing methods, and that they occur for both novice and expert managers.

More specifically, the experimental findings reported here provide strong support for several conclusions about the biases that occur when people use numerical information as the basis of budget allocation decisions. First, graphical presentations that follow current recommendations for the appropriate display of data do not eliminate or reduce the types of heuristic-dependent biases that Hutchinson and Alba (1997) found for data presented in tables. In fact, the use of line charts, in particular, appears to increase the use of difference-based heuristics and the extremeness of the biases they create. Second, as in the Hutchinson and Alba studies, the distributions of types of heuristic used reveal considerable heterogeneity. In fact, the distributions are clearly bimodal. This suggests that best-exemplars and adjacent-differences heuristics are widely...
used in all conditions, but our experimental effects (especially Semantic Frame) shift the likelihoods with which these heuristics are adopted and line charts increase the magnitude of the bias for people using an adjacent differences heuristic. Third, we also find that these effects are large compared to the known effects of prior expectations.

Because of the large magnitude of these effects, we attempted to debias subjects using several different techniques. Successful debiasing approaches must take into account the source of the bias. Arkes (1991) reviewed a large number of decision biases and classified them into three types based on source of bias and the level of resistance to debiasing. The first type of bias is strategy-based errors. These errors arise from adaptive decision making when people choose a less accurate strategy because it is cost effective. The resulting biases can be removed by changing the incentives to make accuracy more valuable. The second type of bias is association-based errors. These errors result from the associative nature of memory, which sometimes makes irrelevant information salient and important information hard to recall. Confirmation biases, hindsight biases, and overconfidence are examples of association-based errors. These biases are not affected by incentives (“subjects will merely perform suboptimal behaviors with more enthusiasm” Arkes 1991). However, these biases can be reduced by specific cues that make important information easier to retrieve. For example, bias is often reduced simply by instructing subject to “consider the opposite” of their current belief. The third type of bias is perceptual error. This type of error is highly resistant to debiasing interventions and people often still find the “wrong” answer compelling after the “right” answer has been explained to them. Arkes also notes that professional training can also be an effective, though time-intensive, debiasing intervention.

We attempt to debias participants using incentives to combat strategy-based errors, consider the opposite to reduce association-based errors, and a training paradigm to combat perceptual errors. None of these techniques effectively debiased participants, which lends support to the idea that, in graphical formats, the root cause of the bias is perceptual, rather than associative or strategy-based.

Although charts and tables have always been a part of business analyses and presentations, the increased penetration of personal computers, spreadsheets, and user-friendly statistical software runs the risk of making these tools, once reserved for sophisticated analysts, into “decision traps” for the unwary manager. Moreover, the advice of various popular books about how to present numerical information seems unlikely to reduce these risks. In fact, advice to use line charts for time-series data may lead to increased biases due to greater use of locational, difference-based heuristics. Implicit in these results is call for decision support systems that can avoid these traps (see Eisenstein and Lodish 2001) and for research to uncover the biases lurking in the wide range of applications that managers use on a daily basis. Regarding the latter goal, we suspect, the findings reported here are just the tip of the iceberg.

“Holistic Versus Digital Models of Multi-Digit Numerical Comparison”

Manoj Thomas, New York University
Vicki Morwitz, New York University

The classic distance effect phenomenon demonstrated by Moyer and Landeaur (1967) has often been cited as evidence for the proposition that multi-digit numerical comparison process is holistic rather than digital (Hinrichs, Yurko and Hu 1981, Dehaene 1997, Dehaene, Dupouz and Mehler 1990). The holistic model of numerical comparison postulates that when people compare two multi-digit numbers such as 3.53 and 6.65, they first encode these multi-digit numbers as analog representations on an imaginary mental number line. This means that the comparison process does not entail the digits per se, but is based only on the holistic magnitudes as encoded on the mental number line. The digital model (Polotrock and Schwartz 1984), on the contrary, suggests that the multi-digit magnitude comparison process entails a digit-by-digit comparison.

For example, when people compare 3.53 and 6.65, just by looking at the left-most digit they can judge that the latter number is higher than the former. Hinrich’s et al employed the Moyer and Landeaur (1967) experimental paradigm in the context of two-digit number comparison task. The experimental task was simple. Participants had to look at a two-digit number flashed on a screen and respond whether the presented number is higher or lower than 55. Hinrichs et al (1981) examined whether the right digits of two-digit numbers had an affect on the response times. They observed that when participants were asked to judge whether the randomly presented two-digit numbers were higher than or lower than the comparison standard 55, not only the ten’s place digit but also the unit’s place digit had a significant effect on response times. The digital model postulates that while comparing two-digit numbers, such as 76 and 55, the perceiver does not have to consider the right digit to judge that the former is larger. Therefore, the digital model suggests that two-digit numbers with the same left digit should have the same response times. Hinrich et al’s observation that the unit’s place digits affect response times, even when relative magnitude judgments can be made just by considering the ten’s place digits, suggests that participants had encoded and compared multi-digit numbers holistically rather than digitally. These findings were subsequently replicated using response time data collected from French participants (Dehaene et al 1990).

Although the data from these studies by and large supported the holistic model, there were some systematic discontinuities in the reaction time curve, contrary to the predictions of the analog model. Two prominent discontinuities appeared at the boundaries of the decade of the standard. For example, when the comparison standard was 55, reactions time smoothly increased with each unit until 49; but the reaction time to judge the magnitude of 50 was significantly higher than that for 49. Similarly the reaction time to judge the magnitude of 60 was significantly lower than that for 59. Proposing a two-stage model, Hinrichs et al (1981) suggested that when the left digits are different, then participants compared magnitudes holistically; but when left digits are the same (and thus non-diagnostic in relative magnitude judgments), perceivers compare only the right digits. The discontinuities observed could be because when the left digits are same, then perceivers have to activate a more finely calibrated scale to encode the magnitudes represented by the right digits. In three experiments we examine the effects of these discontinuities on magnitude perceptions of Prices and GPAs.

In study 1, we use an experimental paradigm similar to that used by Hinrich’s et al (1981) with the exception that instead of using two-digit numbers we used three digit decimal numbers of the form N.NN. Given the finding that for multi-digit numbers with large digits, people tend to compare numbers digitally (Polotrock and Schwartz 1984), it is worth examining whether these discontinuities manifest with three-digit decimal numbers. Participants were randomly shown numbers ranging between 1.00 and 9.00 and asked to judge quickly whether the displayed number was higher than or lower than 5.50. Consistent with previous studies, we observed that response time for 4.99 was significantly lower than that for 5.00, presumably because the difference between 4.99 and 5.50 was perceived to be larger than that between 5.00 and 5.50. Similarly the response time for 5.99 was significantly higher than
that for 6.00, presumably because the difference between 5.99 and 5.50 was perceived to be smaller than that between 6.00 and 5.50. But the response time for 2.99 was not significantly different from that for 3.00; similarly the response time for 7.99 was not significantly different from that for 8.00. These results suggest that for numbers far away from the decade, fractional numbers are rounded off to the closest round digit number; but for numbers close to the decade boundary, such rounding down does not occur. In Study 2, we examined perceived magnitudes of prices. Similar pattern was observed. Participants rounded numbers to the nearest integer only when the stimulus prices were far away from the reference price. When the stimulus price and reference price were close, then they responded as if they are comparing the prices digit-by-digit. Finally, in study 3, we examined the same effect in the context of students’ perceptions of grade point averages. We again found that participants were prone to rounding numbers to the nearest analog quantity only when the numbers where far away from the comparison standard. Together these results support our proposed two-stage model. When the numerical stimuli were close to the comparison standard, then participants had to activate the finely calibrated scale. In such cases round-off effects do not manifest; $3.99 will be perceived to be significantly lower than $4.00. However, when a large range scale is activated numbers such as $3.99 tend to get rounded off the nearest round digit number; in such cases $3.99 will be perceived to be the same as $4.00.

“How Do We Memorize Prices? A Numerical Cognition Perspective”
Marc Vanhuele, HEC School of Management
Gilles Laurent, HEC School of Management
Xavier Dreze, University of Pennsylvania
Zsófia Kenesi, Budapest University of Economic Sciences

Although the results of price memory surveys, like that of Dickson and Sawyer (1990), have received a great deal of attention and interest in our discipline and provoked a lot of discussion (see Kalyanaram and Winer 1995; Monroe and Lee 1999), remarkably little research has been done on the cognitive processes involved in the perception, storage, updating and retrieval of price information. In the field of numerical cognition, a subdomain of cognitive psychology, a consensus has started to emerge on the way the human cognitive system treats number information (Ashcraft, 1992; Dehaene 1992 and 1997). The implications of these advances in numerical cognition for research on price knowledge have not yet been examined.

Numerical cognition has accumulated considerable evidence of the existence of a dedicated cognitive subsystem for dealing with numerical information. It is very likely that price information passes through this subsystem and examining this proposition is the main objective of our research. If prices are treated like any other number, memory performance for prices should reflect the architecture and processing characteristics of the cognitive system dedicated to number processing. Apart from its theoretical interest, examining this proposition also has practical implications because it implies that specific prices will be more or less likely to be recallable because of the way they are treated by the numerical cognitive subsystem. Recall errors and rounding effects would therefore not be random but, at least in part, systematic. Applying the results of past research in numerical cognition to prices may seem like a logical extension, but it should be noted that price stimuli are very different from the stimuli examined in cognitive psychology. Most research in numerical cognition works with small numbers of one or two digits. In addition, the numbers in most studies have no contextual meaning. Finally, to our knowledge there is no research on numbers with a fractional part (the cents part in prices).

The Triple-Code Model. Central to the area of numerical cognition is the question of how numbers and arithmetic information are represented in the cognitive system and what roles the formats of representation play in numerical processing (Ashcraft, 1992; McCloskey and Macaruso, 1995). As a synthesis of the essential findings of this research, Dehaene (1992) develops a triple-code model in which he proposes that numbers can be mentally represented and manipulated in three different forms, depending on the task at hand. The auditory verbal code is generated by a conversion of the acoustic waveform to a phonological representation in which each number is represented by a sequence of phonemes (e.g., /'thirty/'five/). The visual Arabic code represents numbers on a spatial visual medium based on their written form in Arabic numerals (e.g., 35). The analog magnitude code represents numbers as approximate quantities on a dimension termed the number line (about 35, or somewhere between 30 and 40). An analysis of each of the three codes leads to a set of predictions on the types of errors consumers will make in memorizing prices. At this point our research focuses on the role of the auditory verbal and analogue magnitude code.

Auditory Verbal code. As already shown in the early work of Baddeley and Hitch (1974), the retention in short-term memory of short sequences of digits is often speech-based and depends on a subsystem of short term memory which they called the articulatory loop. By putting a number in the articulatory loop and recycling it, a number can be retained while the other components of working memory remain available for other concurrent tasks. The drawback of using the articulatory loop is that it has a span of only about 2 seconds. An intriguing implication of this memory span limitation of the articulatory loop is that prices that take longer to pronounce are less likely to be kept in the articulatory loop and therefore less likely to be stored in long-term memory. In addition, languages that use longer verbal strings to denote numbers handicap their users in the manipulation of numbers, and therefore prices. We formulate the following hypotheses:

H1. Prices that take longer to pronounce have less chance to be accurately recalled and are more likely to be rounded.
H2. Prices with more syllables have less chance to be accurately recalled and are more likely to be rounded.
H3. Consumers who speak slower have a smaller chance to accurately recall prices that are long to pronounce and are more likely to round those prices.

Analog Magnitude code. Numbers in the analog magnitude code lose precision and are converted to approximate quantities. In addition, these conversions become less precise, the higher the number gets. In the context of price knowledge, this implies that smaller prices are coded with much more precision than larger prices. Absolute recall errors will therefore increase as prices get larger. As a result, we should also observe more rounding for higher prices.

H4. The higher a price, the larger the absolute deviation between the recalled and actual price and the larger the probability of rounding.

Empirical Studies. Data collected from three price knowledge surveys in France, the U.S. and Hungary, and one experiment in France, provide preliminary evidence in to support our hypotheses. Data from the first experiment conducted in France confirm H1 and
H2 and reject H4. In this experiment we manipulate the verbal length of prices and their level and examine how these manipulations affect recall accuracy based on short-term memory. The same experiment will be run in the USA and in Hungary. Our hypotheses predict that the language of the consumer will also affect the probability of unaided recall and the accuracy of recalled prices. We plan to make a demonstration of this effect by making a comparison between three languages: French, English and Hungarian.

REFERENCES


