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Compound risk judgment in tasks with both idiosyncratic and systematic risk: The "Robust Beauty" of additive probability integration

Joakim Sundh*, Peter Juslin

Uppsala University, Uppsala, Sweden

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ABSTRACT

In this study, we explore how people integrate risks of assets in a simulated financial market into a judgment of the conjunctive risk that all assets decrease in value, both when assets are independent and when there is a systematic risk present affecting all assets. Simulations indicate that while mental calculation according to naïve application of probability theory is best when the assets are independent, additive or exemplar-based algorithms perform better when systematic risk is high. Considering that people tend to intuitively approach compound probability tasks using additive heuristics, we expected the participants to find it easiest to master tasks with high systematic risk – the most complex tasks from the standpoint of probability theory – while they should shift to probability theory or exemplar memory with independence between the assets. The results from 3 experiments confirm that participants shift between strategies depending on the task, starting off with the default of additive integration. In contrast to results in similar multiple cue judgment tasks, there is little evidence for use of exemplar memory. The additive heuristics also appear to be surprisingly context-sensitive, with limited generalization across formally very similar tasks.

1. Introduction

1.1. Background

Well over 35 years ago Robyn M. Dawes and colleagues (Dawes, 1979; Dawes & Corrigan, 1974) noted that simplicity need not forsake accuracy of judgment, by noting the "robust beauty of improper linear models". A simple linear model often performs very accurately for prediction, even when the weights are arbitrary or "sub-optimal" and the underlying structure is distinctly nonlinear. Research confirms that people often rely on linear additive models in multiple-cue judgment (Karelaia & Hogarth, 2008) and the emphasis on "simplicity and robustness" is echoed in the present-day research program on "fast-and-frugal heuristics" (Gigerenzer & Brighton, 2009). More rarely, is it appreciated that the same logic also applies to reasoning about probability (Juslin, Nilsson, & Winman, 2009).

The normative framework for probability reasoning is probability theory, but people often seem disinclined to, or unable to, make use of the probability rules, leading to phenomena like the conjunction fallacy (Costello & Watts, 2014; Nilsson, Juslin, & Winman, 2016; Nilsson, Winman, Juslin, & Hansson, 2009; Tentori, Crupi, & Russo, 2013; Tversky & Kahneman, 1983) and base rate neglect (Gigerenzer & Hoffrage, 1995; Koehler, 1996). Most research so far has concerned independent probabilities. One could, however, argue that in real life dependencies are the rule rather than the exception, and indeed some have done so (Brunswik, 1952). On the one hand, dependencies between the events add a new layer of complexity to the computations with probability theory, impeding its application to many real-life problems. On the other hand, it seems that people often do not make use of probability theory in the first place. Therefore, although at first glance it may seem reasonable to assume that dependencies will affect people's probability judgments adversely, this need not be the case.

In this study, we investigate the inclination to integrate information by additive integration (Juslin et al., 2009) and its consequences for compound probability judgment. We first introduce a theoretical framework for human judgment (Juslin, Nilsson, Winman, & Lindskog, 2011) and a task involving the assessment of compound risk for multiple assets in a financial market. In this task there are both idiosyncratic risks associated with each asset and (potentially) a systematic risk affecting all assets, as typical of real markets (Bodie, Kane, & Marcus, 2013). We explore the accuracy of the cognitive processes suggested by this framework in tasks with a varying degree of systematic risk. Thereafter, we report the results of three experiments that investigate if people address the tasks with the most effective heuristics and if this can be used to predict their performance in the different tasks.

* Corresponding author at: Department of Psychology, Uppsala University, P.O. Box 1225, SE-751 42 Uppsala, Sweden.
E-mail address: joakim.sundh@psyk.uu.se (J. Sundh).

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1.2. Compound probability and multiple-cue judgment

Compound probability, in its simplest form, involves either a conjunction (the probability that *all* of a number of possible outcomes occur) or a disjunction (the probability that *one or more* of a number of possible outcomes occur). According to probability theory, the probability $p(E_c)$ of a conjunction E_c of n independent events e_i ($i = 1\ldots n$) is calculated by:

$$p(E_c) = \prod_{i=1}^{n} p(e_i), \tag{1}$$

and the probability $p(E_d)$ of a disjunction E_d of n independent events e_i is calculated by:

$$p(E_d) = 1 - \prod_{i=1}^{n} (1 - p(e_i)). \tag{2}$$

A compound probability task is a special case of a multiple-cue judgment (Juslin, Lindskog, & Mayerhofer, 2015) where the elementary probabilities are the cues and the compound probability is the criterion. While multiple-cue judgment may involve various metrics and functional relations, compound probability implies specific constraints; the cues must represent probability measures (i.e., proportions) that are integrated according to probability theory. A person who knows probability theory will thus approach the task with certain preconceptions, for example, that probabilities are never lower than 0 or higher than 1. More knowledgeable assessors may know the rules in Eqs. (1) and (2).

In multiple cue judgment people tend to integrate cues in a linear and additive manner (Brehmer, 1994; Cooksey, 1996; Hammond, 1996; Hammond & Stewart, 2001; Juslin et al., 2009; Karelaia & Hogarth, 2008). Although additive integration violates probability theory, it coincides with how people often approach compound probability. For example, as expected if the judgments derive from a mean, people tend to overestimate conjunctive probabilities and underestimate disjunctive probabilities (Bar-Hillel, 1973; Brockner, Paruchuri, Chen Idson, & Higgins, 2002). This is not universal however. In Doyle (1997) where the participants judged cumulative risk over time, they overestimated *both* conjunctive and disjunctive probabilities. Doyle also found much heterogeneity in the self-reported strategies, including additive or truncated additive strategies as well as anchoring and adjustment (Tversky & Kahneman, 1974). More recently, Juslin et al. (2015) found that participants initially approached both conjunctive and disjunctive probability judgment tasks with a mean heuristic. Following feedback participants switched to a summation heuristic or, in the case of conjunctions, to a (more or less successful) application of the rule from probability theory (Eq. (1)). Notably, when the probability estimates are based on small samples (are "noisy") also simple linear heuristics violating probability theory are capable of impressive accuracy (Juslin et al., 2009).

People thus display a variety of response patterns that are often inconsistent with probability theory. Several accounts for these discrepancies have been proposed, including, use of intentional heuristics (Tversky & Kahneman, 1983), additive heuristics (Juslin et al., 2009), Bayesian sampling (Sanborn & Chater, 2016), inductive confirmation (Tentori et al., 2013), quantum information-processing (Busemeyer, Pothos, Franco, & Trueblood, 2011), and random noise (Costello, & Watts, 2016). In contrast to accounts emphasizing a *single* mechanism, but in line with research on multiple-cue judgment (e.g., Hoffman, von Helversen, & Rieskamp, 2014, 2016; Juslin, Karlsson, & Olsson, 2008), categorization (Ashby & Rosendal, 2017; Ashby & Valentin, 2017), and verbal reports of different strategies (Doyle, 1997; Svenson, 1985), we expect compound probability judgment to contingently draw on one of *several different* cognitive resources that emphasize processes of reasoning, judgment, and memory.

1.3. Cognitive processes in human judgment

Dual Processing Theory (Evans, 2008, 2011; Kahneman & Frederick, 2002) posits that human judgment derives from two distinct processes in which one (Type 1) is fast and intuitive, and the other (Type 2) is slow and analytic. Type 2 processes are typically aligned with use of normative rules, while Type 1 processes are aligned with heuristics. A limitation of this view is that any real behavior is likely to involve both Type 1 and Type 2 processes. These two processes are thus not always easy to separate when applied to behavior and both types of processes may conceivably be the cause of biased judgment (Evans, 2011).

As an alternative, we have proposed a framework for research on judgment that conceptualizes human judgment as arising from three generic cognitive processes, roughly corresponding to reasoning, intuitive judgment, and memory (Juslin et al., 2011). These processes cover the entire functional arc from cues to judgment and will typically involve both Type 1 and Type 2 processes to some extent. The processes are "generic" in the sense that it is not the mathematical details of how they are implemented in a specific study that is the central claim or concern. Rather they are place holders for classes of cognitive resources that people can draw on to make a judgment, and the hope is that the implementations used in a specific study is close enough to the "real processes" to successfully identify the correct type of process, viz. emphasizing judgment by analytic reasoning, intuitive cue integration, or memory.

In *analytic judgment*, the cues are integrated according to retrieved declarative rules and facts. In the case of probability, this likely involves recalling and applying the rules of probability theory. Although people often have a basic understanding of these rules and principles, these "number crunching" processes are likely to be constrained by the capacity of working memory and by the availability of external computational tools, such as calculators or pen and paper. *Controlled intuitive judgment* involves considering the cues in a controlled sequential manner, in effect considering one cue at a time, adjusting the criterion accordingly (see e.g., Hogarth & Einhorn, 1992). The cues are typically explicit in the process, but the integration rule is "implicit" in the sense that it emerges from the sequential and memory-constrained adjustment (Juslin et al., 2009). This process is unsuitable to perform the multiplicative integration in probability theory, as this requires taking previous cues into consideration when an adjustment is made[1]. The default result from these processes is a linear and additive integration of probabilities. *Exemplar memory* is based on recall of previously encountered situations and a comparison to the current situation (Juslin et al., 2008; Nosofsky & Johansen, 2000). In compound probability judgment, this implies high accuracy when there are similar exemplars with known cue and criterion values in memory, but an inability to extrapolate outside of the previously observed distribution of values (see, e.g., DeLosh, Busemeyer, & McDaniel, 1997; Juslin et al., 2008 for a discussion).

A relatively large body of literature by now demonstrates that people shift systematically between these processes as a function of task properties (e.g., Hoffman et al., 2014, 2016; Juslin, Olsson, & Olsson, 2003; Juslin et al., 2008; Karlsson, Juslin, & Olsson, 2007; Pachur & Olsson, 2012; Platzer & Bröder, 2013; von Helverson & Rieskamp, 2009) and properties of the decision maker (e.g., Hoffman et al., 2014; Little & McDaniel, 2015; von Helversen, Mata, & Olsson, 2013). In very simple compound probability tasks, where the context triggers mathematical knowledge, we expect people to sometimes engage in analytic reasoning and use probability theory; in general on the simplifying assumption that the events are independent. But in most

[1] For example, when contemplating the adjustment implied by being presented with probability .9 in a conjunctive task, the adjustment implied by probability theory is different depending on if the previously attended probability (cue) was .9 (subtract .09 to yield .81) or .1 (subtract .01 to yield .09).