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Expectation formation in an evolving game of uncertainty: New experimental evidence☆

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ABSTRACT

We examine the nature of stated subjective probabilities in a complex, evolving context in which participants are not told what the actual probability is: we collect information on subjective expectations in a computerized car race game wherein participants must bet on a particular car but cannot influence the odds of winning once the race begins. In our setup, the actual probability of the good outcome (a win) can be determined based on computer simulations from any point in the process. We compare this actual probability to the subjective probability stated by participants at three different points in each of six races. In line with previous research in which participants have direct access to actual probabilities, we find that the inverse S-shaped curve relating subjective to actual probabilities is also evident in our far more complex situation, and that there is only a limited degree of learning through repeated play. We show that the model in the inverse S-shaped function family that provides the best fit to our data is Prelec's 1998 conditional invariant model. We also find that individuals who report a greater degree of ambiguity are more pessimistic and less responsive to actual changes in real probabilities.

> *Although its empirical picture has come into focus, the weighting function has remained a somewhat tricky object to analyze—at least in comparison with the utility function . . . Overall, it does not look like a shape that one would draw unless compelled by strong empirical evidence.* (Prelec, 2000, p. 67)

1. Introduction

The quality of human judgment has been comprehensively explored in various disciplines, including psychology, management, and economics. The vast literature on non-expected utility theory (see Starmer, 2000; Starmer, 2004 for a review) originated in the persistent inability of rational models of behavior (von Neumann et al., 1947) to predict choice behavior in

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experiments (Camerer and Loewenstein, 2004) which spawned a cottage industry of experiments to tease out individuals' cognitive biases.

One prominent finding from this literature is that even when told the actual probabilities associated with outcomes, individuals behave as though other probabilities apply. Early experimental work by Preston and Baratta (1948), for example, identified an inverse S-shaped function in which subjective (psychologically-mediated) probabilities exceed objective (mathematical) probabilities, p, at low values of p, but fall short of objective probabilities at high values of p. Preston and Baratta (1948) core proposal was that the crossing point in their experimental data—the point at which the subjective and objective probabilities were equal—was a function of an initial anchoring level, which itself may relate to inherent psychological or physiological attributes and an individual's initial position (p. 191–192). In their experiment, the inverse S-shape was not only visible in student data but also in data capturing the behavior of faculty of mostly professorial rank in the fields of mathematics, statistics, and psychology: participants who presumably were well-acquainted with probability theory. Subsequent work by Dale (1959) also reported that experimental participants tend to overestimate low probabilities and underestimate high probabilities.

Since then, a raft of theories—including prospect theory Kahneman and Tversky (1979), rank-dependent utility theory (Quiggin, 1982); Schmeidler, 1989; Wakker, 1994; Yaari, 1987), adaptive probability theory (Martins, 2006), and conditional small world theory (Chew and Sagi, 2008)—have proposed specific cognitive decision rules regarding how subjective probabilities are derived from objective ones. Contrary to expected utility (EU) theory, however, these approaches treat actual probabilities as nonlinear inputs to subjective probabilities. Moreover, despite being axiomatically based, each has become associated with a particular probability-weighting function that relates the subjective probability p^s to the true probability p. These weighting functions can accommodate the psychophysics of diminishing sensitivity, wherein the marginal impact of a stimulus diminishes with increasing distance from a reference point (Camerer, 1995; Fox and See, 2003; Tversky and Kahneman, 1992). They can also allow for affective aspects of the decision process, such as hope (when contemplating high-probability losses) or fear (when contemplating low-probability losses); emotionally richer decision-making settings, for example, may give rise to more pronounced inverse S-shapes (Rottenstreich and Hsee, 2001; Trepel et al., 2005).

1.1. Broader context and contribution

A key methodological divide in work examining subjective probability formation concerns whether participants have direct access to objective probabilities. One branch of literature aims to estimate a probability weighting function based on informing individuals of an outcome's true probability, and then observing their choice behavior (see, e.g., Abdellaoui et al., 2011; Gonzalez and Wu, 1999; Kilka and Weber, 2001). Such studies were criticized by Fox and Tversky (1998): 'Although most empirical studies have employed risky prospects, where probabilities are assumed to be known, virtually all real-world decisions (with the notable exception of games of chance) involve uncertain prospects (e.g., investments, litigation, insurance) where this assumption does not hold. In order to model such decisions we need to extend the key features of the risky weighting function to the domain of uncertainty' (p. 880). In a similar vein, Abdellaoui et al. (2011) state,'[i]n many situations we do not know the probabilities of uncertain events that are relevant for the outcomes of our decisions' (p. 695). Simply put, in the real world people typically face decisions characterized by partial knowledge of the consequences of their actions Tversky and Fox (1995). However, empirical tests in real-world situations are fraught with identification problems Gilboa et al. (2008). Lab experiments offer more control, though they have been criticized as somewhat artificial Winkler (1991).

In this paper, we confront participants with scenarios whose complexity and uncertainty mimics those aspects of real-life decision-making contexts, in which the actual probability of success is not within individuals' feasible information set. We then estimate the probability weighting function using data drawn from repeatedly asking individuals for their estimates of the probability of a good outcome. While it is not impossible to correctly ascertain the actual probability of a good outcome, it is extremely difficult. Hence, as with many economic problems, probabilities are not truly given (see Gilboa et al., 2008). The objective probabilities we use are drawn from computer simulations of how each uncertain situation, on average, will play out from the point in time at which subjective probabilities are elicited.

The quality of people's assessments, their abilities, and the limits of their functioning in uncertain environments are all of theoretical and applied importance (Lichtenstein and Fischhoff, 1977). We contribute to the literature examining people's intuitive judgements of likelihood (Gilovich et al., 2002), estimating the probability weighting function in the case of uncertainty (see, e.g., Abdellaoui et al., 2011; Baillon et al., 2012; Fox and Tversky, 1998; Holt and Smith, 2009; Kilka and Weber, 2001; Tversky and Wakker, 1995; Wakker, 2010). We also contribute to a broader literature on the relationship between subjective probabilities and actual outcomes (see, e.g., Brenner et al., 2002; Carman and Kooreman, 2014; Hurd, 2009; Manski, 2004). Overall, studies using survey data dominate this literature (de Palma et al., 2008). In our paper, by contrast, we construct an adaptation for the experimental laboratory of a race car game, in which participants must bet on the race's ultimate outcome, which cannot be influenced once the game is underway. We ask participants several times during each race what they think the odds are of their chosen car winning the race. Our set-up is thus dynamic—like the few existing papers (e.g., Cheung, 2001) that examine dynamic, probabilistic processes over time—and allows us to monitor how agents update their probability expectations as a risky situation unfolds. This is an important feature of the study, as many interesting decision-making problems are dynamic in nature (Winkler, 1991). Further, as Machina and Schmeidler (1992) point out (p. 746), "... real-world uncertainty seldom presents itself in terms of exogenously specified probabilities, but rather,