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Prospect balancing theory: Bounded rationality of drivers' speed choice

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ABSTRACT

This paper introduces a new approach to model the psychological determinants of drivers' speed choice: prospect-balancing theory. The theory transfers psychological insight into the bounded rationality of human decision-making to the field of driving behaviour. Speed choice is conceptualized as a trade-off between two options for action: the option to drive slower and the option to drive faster. Each option is weighted according to a subjective value and a subjectively weighted probability attributed to the achievement of the associated action goal; e.g. to avoid an accident by driving more slowly. The theory proposes that the subjective values and weightings of probability differ systematically from the objective conditions and thereby usually favour a cautious speed choice. A driving simulation study with 24 male participants supports this assumption. In a conflict between a monetary gain in case of fast arrival and a monetary loss in case of a collision with a deer, participants chose a velocity lower than that which would maximize their pay-out. Participants' subjective certainty of arriving in time and of avoiding a deer collision assessed at different driving speeds diverged from the respective objective probabilities in accordance with the observed bias in choice of speed. Results suggest that the bounded rationality of drivers' speed choice might be used to support attempts to improve road safety. Thus, understanding the motivational and perceptual determinants of this intuitive mode of decision-making might be a worthwhile focus of future research.

1. Introduction

It is widely accepted that choices under risk are usually not guided by pure rationality but are often based on intuition which is better described in terms of emotions rather than cognitions (e.g., Kahneman, 2003; Gigerenzer, 2007). Since Simon (1955) called for a modification of the theory of "economic man", research has accumulated considerable knowledge about the principles that rule the bounded rationality of human decision-making. A reliable finding from psychology, economics, and finance is that people often tend to avoid risks and losses (Kahneman et al., 1991; Rabin and Thaler, 2001). Thus, they prefer decision options with more predictable consequences and are reluctant to accept options involving a potential loss even if the alternative option would promise a higher payoff. The present paper transfers this knowledge to the field of drivers' speed choice. The approach aims to improve the comprehension of the psychological factors that favour careful driving behaviour.

An intuitive mode of decision making is particularly required in situations in which not all relevant information is available and the processing time is limited (Sivak, 2002). This characterization applies to many driving situations. The interplay of vehicle, road, weather, and other road users forms a complex and rapidly changing environment that is often not totally predictable for the driver. Accordingly, the concept of bounded rationality has already been discussed in the context of merging into traffic (Sivak, 2002) and car following (Lubashevsky et al., 2003). However, drivers' speed choice is a particularly interesting field of application because velocity is one of the most important factors in accident risk (Aarts and Van Schagen, 2006). Therefore, it is paramount to understand drivers' decision making related to speed.

1.1. Outline of the prospect balancing theory

Tarko (2009) proposed a model of drivers' speed choice in which the preferred speed results from a trade-off between three disutilities: crash risk, time loss and risk of a speeding fine. Because these disutilities are assumed to depend on drivers' preferences and perceptual abilities, the model claims to comprise the concept of bounded rationality (in contrast to O'Neill, 1977). The present paper advances this idea by outlining a decision theory of drivers'

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speed choice. However, instead of focusing on a limited set of disutilities, the theory claims to be valid for the high diversity of goals that might guide drivers' speed choice. Therefore, the theory concentrates more on the basic psychological principles that determine how the pursuit of an action goal is implemented in the choice of speed. These principles are derived from general knowledge about human decision-making. Prospect theory (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992) is one of the most prominent approaches to describe the bounded rationality of judgments and choices in uncertain situations. Therefore, this theory is used as a frame of reference to conceptualize drivers' decision-making.

Applying prospect theory to the field of driving behaviour requires acknowledging that speed choice differs from common decision problems investigated in psychological research. In contrast to the discrete decision alternatives, e.g. of a lottery, driving speed is a continuous dimension. Given that information processing capacities are limited, it is not realistic that drivers consider the full range of different speeds and their potential outcomes in their decision-making. However, from a given driving speed, drivers have two options for altering velocity: accelerate or decelerate. It is assumed here, that only these two options are considered in speed choice. Usually accelerating increases the probability of a positive outcome (e.g. arriving in time) whereas decelerating decreases the probability of a negative outcome (e.g. a speeding fine). Thus driving requires a trade-off between these two desirable prospects rather than a discrete choice. Accordingly, the application of prospect theory to drivers' speed choice is called prospect balancing theory.

Prospect balancing theory proposes that a driver attributes a subjective total value to each of the two speed change options. With increasing velocity the total value of the acceleration option decreases whereas the total value of the deceleration option increases. The model predicts that the driver chooses a speed at which both total values are equal. Each total value is defined by the product of two variables: the subjective value and the subjective efficacy of the respective speed-change option. In terms of prospect theory, these variables correspond to the subjective weight and the subjectively weighted probability with which potential outcomes are considered in the evaluation of a decision option. The following sections describe these concepts.

1.1.1. Subjective values

Drivers execute the driving task with certain aims and tendencies to reach these aims: drivers' action goals. In respect to velocity many different goals might be involved. Most of these goals split into those that tend to be achieved by driving quickly (e.g. thrill of speed, fast arrival, impressing others) and those that are favoured by driving slowly (e.g. accident prevention, speeding fine avoidance). Because of the well-known tendency to simplify decision problems (editing phase, Kahneman and Tversky, 1979) it is proposed that drivers usually reduce their speed choice to a trade-off between two action goals: the most prominent goal related to fast driving and the most prominent goal related to slow driving. Which goals come to the fore depends on the driver and the driving situation and therefore might be influenced by personality traits on the one hand and the current task demands on the other hand.

The achievement of an action goal has a particular value to the driver. One way to quantify this value would be to describe it by means of objective parameters (utilization worth of the vehicle, number of passengers, number of heart beats per minute); however, these parameters are hardly comparable. Moreover, it is reasonable to doubt that there is a linear relationship between these parameters and their subjective importance (e.g. relation between the number of passengers and drivers' sense of responsibility). In line with prospect theory, it is therefore assumed that drivers attribute subjective values to the achievement of their action goals. These subjective values provide a common basis for the comparison of different kinds of action goals. However, they diverge systematically from the numeric values of the respective objective parameters. The direction of these deviations can be deduced from prospect theory (e.g., Kahneman and Tversky, 1979). Fig. 1a illustrates two characteristics of the proposed relationship. First, an increase in objective value has a declining impact on the increase in subjective value. This implies, for example, that an increase in speeding fine from €50 to €100 should have a stronger impact on the re-evaluation of the speed options than an increase from €200 to €250. A second characteristic of the relationship is that the subjective value depends on whether an outcome is perceived as a loss or a gain. Thereby a loss is usually attributed a substantially higher subjective value than an equivalent gain. For instance, this implies that €100 which are lost in case of late arrival should act as a stronger motivator for speeding than €100 which are gained in case of arriving in time.

Prospect balancing theory is in line with many models of driving behaviour in assuming that speed choice depends on conflicting action goals or motivations (e.g., Wilde, 1982; Fuller, 2005; Zuckerman, 2007; Koornstra, 2009). However, in contrast to most of these models the theory does not propose that drivers' perceived risk of having an accident or of losing control is always involved in speed choice.

1.1.2. Subjective efficacy

Drivers favour the achievement of one of their two dominant action goals by either decelerating or accelerating. Thus, if they only considered the subjective value of these goals they would either stop driving or choose the maximum speed, depending on which goal's value prevails. Usually the benefit of further acceleration or deceleration decreases, however, the more the speed has been already changed. Thus, prospect balancing theory proposes that drivers' evaluations of the speed-change options additionally include the subjective estimation of each option's potential effectiveness in achieving the associated action goal. This is called the subjective efficacy. In line with the assumption that speed choice is determined by two predominant action goals, it is assumed that two kinds of subjective efficacies are considered: one related to acceleration and one related to deceleration. The subjective efficacy of a speed-change option depends on the parameters of the driving task. For instance, for a driver seeking to arrive on time, the subjective efficacy of the acceleration option might depend on the perceived ratio between the distance to the destination and the available time. If all other parameters of the driving task are constant, the subjective efficacy predominantly varies with the driving speed. Fig. 1b shows a hypothetical example of how the relationship between velocity and subjective efficacies might look for a given driver and driving situation. It is proposed that the subjective efficacy of a speed-change option correlates negatively with drivers' current certainty of achieving the associated action goal. This involves some general assumptions about the relationship between efficacy and speed.

- Usually the subjective certainty of achieving a velocity-related action goal increases with velocity. Thus, the subjective efficacy of the acceleration option decreases with the driving speed. On the other hand, the subjective certainty of achieving a safety-related action goal decreases with increasing velocity. Therefore, the subjective efficacy of deceleration option increases with driving speed.
- Subjective efficacy varies between a value of zero and a particular maximum value. A zero efficacy is reached at speeds at which further acceleration or deceleration does not increase the subjective confidence of goal achievement (e.g. beneath the speed limit deceleration has zero efficacy for avoiding a speeding fine). The maximum subjective efficacy is reached at speeds at which