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Impact of risk attitudes and perception on game theoretic driving interactions and safety

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ABSTRACT

This study employs game theory to investigate behavioural norms of interaction between drivers at a signalised intersection. The choice framework incorporates drivers' risk perception as well as their risk attitudes. A laboratory experiment is conducted to study the impact of risk attitudes and perception in crossing behaviour at a signalised intersection. The laboratory experiment uses methods from experimental economics to induce incentives and study revealed behaviour. Conflicting drivers are considered to have symmetric disincentives for crashing, to represent a no-fault car insurance environment. The study is novel as it uses experimental data collection methods to investigate perceived risk. Further, it directly integrates perceived risk of crashing with other active drivers into the modelling structure. A theoretical model of intersection crossing behaviour is also developed in this paper. This study shows that right-of-way entitlements assigned without authoritative penalties to at-fault drivers may still improve perceptions of safety. Further, risk aversion amongst drivers attributes to manoeuvring strategies at or below Nash mixed strategy equilibrium. These findings offer a theoretical explanation for interactive manoeuvres that lead to crashes, as opposed to purely statistical methods which provide correlation but not necessarily explanation.

1. Introduction

Individual choice and its implications on safety have been studied at length both from a theoretical (Dixit, 2013; Tarko, 2009) as well as an empirical[1] perspective. Individuals are assumed to choose under a utility maximization framework, where they evaluate the utilities of the alternatives with regards to the perceptions of risk (or the belief of the probability of occurrences of the alternatives). Crash risk perception is a factor that has been used in theoretical models of driver operational behaviour and manoeuvres (Dixit, 2013; Dixit et al., 2014; Hamdar et al., 2008; Tarko, 2009).

Structural decision models incorporating risk perception were developed to model free flow speeds (Tarko, 2009). Risk perception was treated as a function of different road layouts, and it was found that lane widths, presence of sidewalks and intersection density all increase perceived risk. Gap acceptance to perform a left/right turn was likewise modelled using structural decision models (Dixit et al., 2014). By regressing gap acceptance against manoeuvres observed in a driving simulator, it was found that perceived risk changes with experience and skill. A similar study of macroscopic behaviour found risk perception to be different across different network characteristics (Dixit, 2013). Treating risk perception as a latent factor has been complemented by studying statements of drivers' risk perception using survey questionnaire methods (Bijkerk, 2007; Figueroa, 2005; Louca et al., 2000; Otković et al., 2013; Rundmo and Iversen, 2004).

The quasi-induced exposure method is widely used to identify exposure of specific population groups by characterizing drivers as at-fault or not at-fault, and then assuming that the distribution of not at-fault drivers is representative of the driving population at the location of interest. (Chandraratna and Stamatiadis, 2009; Jiang and Lyles, 2010; Mendez and Izquierdo, 2010; Dixit and Rashidi, 2014). However, if certain groups of population have skewed perceptions of risk in their driving interactions, they might have radically different not-at-fault involvements than average drivers. Therefore, there is a need to better understand the role of risk attitudes and perceptions in interactions and eventually on the likelihood to crash.

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[1] Driving simulator and field experiments

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Further, driving is naturally an interactive task, where individual drivers are continuously manoeuvring based on expectation and beliefs regarding actions of other drivers. Game theory provides an ideal foundation to mathematically model decisions in an interactive environment (Myerson, 1991). Elvik (2014) carried out an extensive review of applications of game theory to traffic safety, identifying a limited literature and the need to further explore these concepts in relation to traffic safety.

Game theory has been used to explain norms of driver behaviour that sometimes contradict road rules (Elvik, 2014). It has particularly been used to model context-specific interaction between roads users, such as: between police and speeding vehicles (Bjørnskau and Elvik, 1992), merging and cooperation in lane changing manoeuvres (Kita, 1999), choice of vehicle size (Tay, 2002) and choice of evasive manoeuvres (Prentice, 1974). Game theory has also been used to formulate general models of interaction between road users (Pedersen, 2001, 2003). Sugden (1998) also makes reference to behavioural norms influencing interactions at an intersection which deviates from pure self-interest. However, these models do not incorporate the role of individual risk attitudes and perceptions on interactions and potential crashes.

To address this gap, this paper employs game theory to investigate the interaction between drivers at a signalised intersection, while studying the effects of individual risk attitudes and risk perception. Interaction at a signalised intersection can be modelled as a game where paired drivers must coordinate their crossing behaviour in order to avoid crashing into each other. Each paired driver receives incentives for successfully crossing the intersection, and penalties for crashing into the conflicting driver.

To the best of the authors' knowledge, this study is the first time that risk attitude and risk perception of crashing into other *active* drivers is investigated. This is also the first time that risk perception is studied using experimental data collection methods. To study the impact of risk attitudes and beliefs, a controlled economic experiment was undertaken to isolate[2] the impact of these behavioural factors on the choice of *go or not go* at a signalized intersection.

The rest of the paper is structured as follows. First the design of the experiment is explained. A descriptive analysis of the collected data is presented next, followed by a discussion about the methodology of estimation of the structural decision model. Following the methodology section, the modelling results and interpretation of the findings are provided. Finally, a summary with a discussion about future research directions is included.

2. Experimental design

A controlled laboratory setting with incentivised choice tasks was used to infer behaviour in this study. Elicited preferences in incentivised experiments are based on actual choices being made for real (monetary) consequences. This provides a high degree of control in a laboratory setting to study individual preferences (Dixit et al., 2014; Holt and Laury, 2002).

The experimental structure involved utilising three incentivised choice tasks:

- An intersection choice task representing driving at a signalised intersection, with two treatments with respect to the amount of incentives.
- One Holt and Laury lottery choice task (Holt and Laury, 2002)

Subjects participated in a signalised intersection choice task involved in a binary decision making process, i.e., to either drive through the signalised intersection or to stop and wait at the signalised intersection. In this scenario, one driver experienced a green signal while the other experienced a red signal. The outcome of these decisions resulted in either a gain or loss in income, which was dependent upon the simultaneous decisions made by both the subjects.

The Holt and Laury lottery choice task was administered at the end of the two intersection choice tasks. The Holt and Laury lottery choice task is used to elicit subjects' risk attitude. It is important to control for the risk attitude of drivers in order to correctly estimate their risk perception (Dixit et al., 2014).

The Holt and Laury lottery choice task contains a menu of paired lottery choices. The subjects are faced with a binary decision; an 'A' or a 'B' lottery. The choice over the lotteries reveals their risk preferences. An excerpt of the Holt and Laury lottery choice task presented to subjects is presented in Fig. 1.

In addition to completing the above tasks, participants were required to fill out a demographic questionnaire. The demographic questionnaire was completed after the two intersection manoeuvre choice tasks and before the Holt & Laury task to provide subjects with a break. The responses from the demographic questionnaire were used to identify personal attributes correlated to crash risk perception and risk attitude.

In addition to incentives provided in the experiment, subjects were given a fixed amount of $5 as participation fees and an additional initial endowment of $8 to cover losses which might have occurred during the experiment.

The design of the experiment instructions and questionnaire referred to Loewenstein (1999) to ensure that the issues of contextual cues, incentives, anonymity and repetition of tasks in the experiment were addressed. The experiment instructions and questionnaire are included in the appendices of this paper.

2.1. Intersection choice task

Participating subjects in the experiment were randomly paired, such that there were two subjects at an intersection. They were placed at conflicting intersection approaches and had to coordinate their behaviour in order to avoid accidents. The pair's simultaneous co-decisions determined their payoff. Since random drivers meet at intersections, a random subject pairing design was selected. A schematic diagram of the intersection is included as Fig. 2.

One paired subject took the role of a driver approaching the signalised intersection when their signal was about to turn red. They shall be referred to as the Red drivers. The other subject was a stationary driver at a conflicting approach waiting for their signal to turn green. They shall be referred to as the Green drivers.

Each driver had to make either of two choices; to "drive" or "wait". For Red drivers, to "drive" meant running the red light and driving through the intersection and to "wait" meant stopping at the intersection.

For Green drivers, to "drive" meant to drive through the intersection as soon as their signal turned green, while to "wait" meant, to stop after their signal turned green to allow for a potential red light running vehicle. Subjects were also told that there would be no police supervision or red light cameras present, to reflect the limited enforcements.

There were two treatments that varied the payoff functions to evaluate the robustness of the findings, one was with a low incentive to drive (Table 1) and the other with a high incentive to drive (Table 2). The payoffs for their decisions are shown in Tables 1 and 2.

[2] Other behavioural factors such as impatience and distraction also influences driving behaviour. Therefore, in this study we use the experimental method to isolate and evaluate the impact of the risk attitudes and beliefs on red light running choices.