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An endogenous lottery-based incentive mechanism to promote off-peak usage in congested transit systems

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ABSTRACT

In this paper, we evaluate a lottery-based revenue-neutral incentive mechanism to reduce the congestion in urban transportation systems. Specifically, we test the use of random lottery-based reward schemes to promote public transit usage during off-peak periods. We derive the theoretical equilibrium for this decision-making game and test the validity of the proposed mechanism through monetized laboratory experiments. We use methods from experimental economics to investigate the behavioral assumptions within such an incentive-based mechanism. We find counterintuitive results where a Pure Nash Equilibrium explains behavior in one regime and Quantal Response Equilibrium explains behavior in another regime. Specifically, there is no shift to off-peak periods when the expected value of traveling in the off-peak is less than that at peak, which is explained by a Pure Nash Equilibrium. However, there is a substantial shift to the off-peak period when the expected value of traveling in the off-peak is larger than that of the peak, but much less than that predicted by a Pure Nash Equilibrium. The Quantal Response Equilibrium performs reasonably well in this condition, and we conclude that risk attitudes play a significant role in explaining behavior in lottery-based incentive mechanisms. This study, which relies on the gamification of travel behavior, finds that the proposed mechanism can provide a sustainable shift in users' choices.

1. Introduction

Improving urban congestion and reducing CO_2 emissions stands at the core of the "smart city" concept (Directorate General for Internal Policies, 2014) and have been the focus of many research efforts over the past decades. Unfortunately, individual rational behavior usually results in inefficiency in social outcomes, especially in transport networks (Wardrop, 1952; Vickrey, 1969). In the transport literature this phenomenon has been discussed at length as the gap between user equilibrium and system optimal behavior. Governments and city councils have traditionally relied on pricing schemes such as tolls and taxes, to internalize these externalities of congestion associated to increased delays and crowding (de Palma and Robin, 2011; Li and Hensher, 2011). When implemented, urban road pricing solutions have often been shown to improve the traffic situation, as in the Norway case (Langmyrh, 2001), or to reduce emissions, as in the London case (Beevers and David, 2005). More generally, there is a clear attempt worldwide to develop and justify technical solutions to implement new road charging schemes (Litman, 2013). However, these policies are often unpopular and hard to garner acceptability, as well documented in the case of the Stockholm congestion pricing scheme (Eliasson, 2009). Further, the study of feasibility of congestion pricing in New York concluded that (Schaller, 2010) "…*to maximize public acceptance, demonstrations could start with a voluntary opt-in phase, thus showing system benefits before any drivers are required to switch to a mileage-based system…*". In a synthesis report, a team at the Victoria Transport Policy Institute identified the need to experiment with the pricing of transport (Litman, 2010): "…*Easier reforms, such as pay-as-you-drive insurance and registration fees, cash out parking and congestion pricing of existing road tolls should be implemented first, with gradual increases in parking fees, weight-distance fees and emission fees over time. The price sensitivity of driving is more evident when measured with respect to parking fees and tolls… A modest parking or road fee can significantly influence travel demand…*". The Rand Corporation in the United States published a report (Sorensen et al., 2009) with similar findings. In the Netherlands, a peak rewarding project known as the Spitsmijden experiment was tested on four corridors

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to investigate the behavioral responses of personal vehicle users towards incentives to shift their departure times to less-congested periods (Bliemer et al., 2009). Although, the reward mechanism was able to mitigate congestion induced by road and bridge maintenance operations; an examination of the non-participants' profiles show that participation in the experiment is primarily related to working time flexibility, constraints in the household and the workplace and especially to

personal motivation rather than to socio-demographic attributes (Ben-Elia and Dick, 2009). Further, the findings of this experiment suggest that participants' disutility – in terms of schedule delay – is almost constant over several weeks (Knockaert et al., 2012). However, an analysis of the departure time patterns before and after ten-week of peak rewarding showed that a majority of travelers recovered their original commuting pattern when the incentive mechanism ended (Ettema et al., 2010). This peak rewarding experiment highlights the importance to design revenue-neutral incentive-based mechanism to ensure a sustainable outcome. Therefore, although urban congestion pricing is a well-founded approach to improve the efficiency of transportation networks, its implementation is a slow process and the potentially negative reaction of the citizens with regards to toll-based schemes often postpones the required political decisions. As an example French leaders have definitively abandoned in 2013 the 'ecotax' road pricing system on heavy goods vehicles that had provoked violent protests among the truck industry.

Recent market research results show evidence on how new businesses that build and nurture online communities can create deeper connections that in turn increase engagement, loyalty and revenue. This is mainly driven by start-up companies involved in fitness centers, health related activities or "greening" behaviors addressing waste and other households domestic activities like energy usage and savings (Munson and Consolvo, 2012; Gnauk et al., 2012). The transportation academic domain and more precisely mobility and trip behavior models have not thoroughly addressed these new dimensions. The advent of innovative communication technologies opens the door to complement the transportation taxing, pricing and valuing historical schemes with a more dynamic approach based on incentivization and gamification of travel behavior and to evaluate the role of the carrot instead of the stick. For instance, loyalty-based incentives known as Frequent Flyer Programs have been extensively used by major airlines over the past decades and have demonstrated their impact on air travel choices mainly for business travelers (Chin, 2002). Knowledge and policies oriented towards mobility behavior changes are now considering the importance of the game context as a potential positive effect. More precisely, gamification refers here to the "use of game design elements in non-game contexts" (Deterding et al., 2011). Thereby, game mechanics are used to motivate individuals and groups to engage in a real world non-game activity (*e.g.* Nike+, Four Square). The attractiveness of the incentives along with embedded game designs may have a combined effect on behavioral changes.

Hence to improve the efficiency of transportation networks, governments and city councils are now turning to policies based on gamification-oriented incentives that have wider acceptability and popularity. These policies have predominantly been shaped by the work of Thaler and Sunstein (Thaler and Sunstein, 2008), who have discussed the creation of a choice architecture to *nudge* people to choices that are socially beneficial. Some of the recent examples are the Infosys-Stanford Traffic project (Merugu et al., 2009); the Singapore smart commuting program (Singapour Incentive Program, 2014); and the incentives for participating in commute clubs in Stanford (Stanford Commute Club, 2014). As an example the Singapore project encourages participants to shift their commute schedules on the Singapore rail system away from overcrowded peak times. The more commuters participate in Insinc, the more opportunities they will have to receive random rewards. Insinc aims to reduce crowded trains by distributing the load, resulting in a more efficient use of Singapore's transportation resources. Despite this increasing interest in incentive-based Traffic Demand Management (TDM), there is no systematic theory or behavioral models to inform the planning and development of these policies and evaluate its impacts.

This paper addresses this gap with the development of a theoretical model to predict user behavior under an incentivized TDM mechanism, and test it in a laboratory setting using methods from experimental economics. Our approach aims at analyzing the choices made by users under an incentivized mechanism. There are a variety of findings and approaches to researching the functionality and impact of incentives to support specific human behavior including in the transportation area (Mccall and Koenig, 2012; Avineri, 2012). Most theories on incentives are based on behavior psychological approaches (Kamenica, 2012) and are used in the area of economics, social psychology and behavior therapy. In this sense an incentive is a motivator that influences an individual to perform a specific action. Incentives can be monetary or nonmonetary rewards and can take a material (*i.e.* gifts) or moral (ethical sanctions) form. In addition, an incentive can trigger an extrinsic or intrinsic motivation to perform a specific action (Bénabou and Jean, 2005).

It is well demonstrated that risk aversion plays an important role in an individual's decision making (Gowdy, 2008; Kahneman and Tversky, 1979). Public transit choices are inherently risky due to congestion effects. In this study, we rely on behavioral economics to develop a theoretical model and test it using experimental economics. The proposed model relies on game theoretic equilibrium while incorporating risk aversion (this is further discussed in Section 4), to study incentive-based TDM policies. Studying the impact of different games on individuals' risk attitudes and their choices in a field setting would have been difficult due to several other external factors influencing users' decisions (*e.g.* comfort, value of time etc.). Therefore, the proposed experimental design relies on conducting controlled laboratory experiments, where the impact of different incentive mechanisms can be evaluated, and their impact on risk attitudes can be studied in a highly controlled manner.

The experiment evaluates the impact of different reward functions on user's travel behavior. Use of methods from experimental economics has recently received an increasing attention in the transportation research community (Dixit et al., 2014). Experimental economics is increasingly being used in the area of transportation research to gain insights into behavior as well as to test theories and develop policies. Though field data provides insights, there is a lack of control, and laboratory experiments with monetary consequences provide the ideal control to test theories and policies, and understand behavioral interactions. The areas of application include, for instance, route choice (Dixit et al., 2013', 2011; Rapoport et al., 2009; Selten et al., 2007); departure time choice (Ziegelmeyer et al., 2008), public transit choice (Denant-Boemont and Sabrina, 2012), safety (Dixit et al., 2012) and travel mode choice (Innocenti et al., 2013). Experimental Economics at its core is driven by Induced Value Theory (Smith, 1976); this provides experimenters the ability to conduct controlled experiments.

Motivated by the field implementation of the lottery-based incentive mechanisms in India (Merugu et al., 2009) and Singapore (Singapour Incentive Program, 2014), we design an experiment to study how such departure-time games influence individual choice and risk attitudes. In particular, we focus on a departure-time game where the reward and the probability of winning the reward depend on the number of people switching to a better alternative that is being incentivized. This poses an interesting question on