Transportation Research Part D 50 (2017) 345–356

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Myopic loss aversion in the response of electric vehicle owners to the scheduling and pricing of vehicle charging

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ARTICLE INFO

Article history:

Keywords:
Electric vehicles
Charging decisions
Smart grid charging
Utility maximization
Myopic loss aversion
Ultimatum two-player game

ABSTRACT

Upward expectations of future electric vehicle (EV) growth pose the question about the future load on the electricity grid. While existing literature on EV charging demand management has focused on technical aspects and considered EV-owners as utility maximizers, this study proposes a behavioural model incorporating psychological aspects relevant to EV-owners facing charging decisions and interacting with the supplier. The behavioural model represents utility maximization under myopic loss aversion (MLA) within an ultimatum game (UG) framework where the two players are the EV-owner and the electricity supplier. Experimental economics allowed testing the validity of the behavioural model by designing three experiments where a potential EV-owner faces three decisions (i.e., to postpone EV charging to off-peak periods for a discount proposed by the supplier, the amount of discount to request for off-peak charging at times decided by the supplier, and the amount of discount to accept for supplier-controlled charging) under two contract durations (i.e., short-term, long-term). Findings from the experiments show that indeed potential EV-owners perform charging decisions while being affected by MLA resulting from monetary considerations and the UG participation, and that presenting long-term contracts help potential EV-owners to curtail MLA behaviour and minimise cost even though the assumption of utility maximization is violated.

1. Introduction

While the market penetration of electric vehicles (EVs) has been negligible so far because of high unit costs, limited driving range, and lack of recharging infrastructure, upward expectations exist for a future rapid EV growth following battery technology innovation and governmental commitment to EV promotion through investments, legislation, and taxation policies (e.g., Andersen et al., 2009; Bonges and Lusk, 2016; Brady and O'Mahony, 2011; Dagsvik et al., 2002; Valeri and Danielis, 2015). Recent demand assessment studies predict reasonable market shares around 4–10% for EVs by 2020 (e.g., Brady and O'Mahony, 2011; Lebeau et al., 2012; Mendes Lopes et al., 2014), and suggest dominant market shares for EVs by 2030–2050 in both Europe and the U.S. (e.g., Lebeau et al., 2012; Mabit and Fosgerau, 2011; Traut et al., 2013).

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http://dx.doi.org/10.1016/j.trd.2016.11.020
1361-9209/

The future EV growth is expected to load significantly the electricity power grid. Charging times are expected to coincide with electricity demand peak hours for household consumption and industrial use (Axsen and Kurani, 2010), and even modest EV shares (20–25% of the total vehicle fleet) are expected to increase the electricity load by roughly 30% (Amoroso and Cappuccino, 2012). Demand side management (DSM) of EV charging in a smart grid by encouraging EV-owners to change their charging patterns in response to changes in the electricity prices is viewed as a possible solution to avoid grid overload at demand peak hours and to avoid investments in grid capacity expansion (Finn et al., 2012; Flath et al., 2014). Economic evaluations have shown that DSM of EV charging has positive welfare effects: smart charging grids in Finland could produce benefits of 227 EUR per vehicle per year (Kiviluoma and Meibom, 2011); shifting charging from peak to off-peak in the U.S. could generate savings ranging from $1.1 billion to $5.1 billion per year (Lyon et al., 2012); price-responsive charging strategies in Singapore could turn estimated losses of 1000 SGD per vehicle per year into estimated profits of 21–130 SGD (Pelzer et al., 2014). Feasibility evaluations have shown that DSM of EV charging translates into smart integration of EVs in the system: agent-based micro-simulation models estimated electricity prices varying with mobility behaviour and optimal charging costs (Dallinger and Wietschel, 2012) and analyzed electricity demand considering EV potential demand and price schemes (Waraich et al., 2013); optimization algorithms proposed efficient EV charging scheduling under system optimization or user utility maximization (e.g., Di Giorgio et al., 2014; Iversen et al., 2014); business models illustrated the efficiency of the optimization algorithms and the benefits of changing EV charging times (e.g., Kley et al., 2011).

The major limitation in the aforementioned models lies in their focus being technical rather than socio-technical. All these studies assume that EV-owners are utility maximizers who, when facing charging decisions, will postpone charging and/or accept charging being controlled by the electricity supplier in return for a discount on charging fees. From the perspective of postponing charging, empirical evidence exists that changing EV charging times could generate anxiety about unforeseen needs to drive that imply mobility constraints and additional costs to overcome them in the case the EV becomes unavailable because uncharged (Bakker, 2011). From the perspective of accepting the charging being controlled by the supplier, empirical evidence exists that individuals prefer simple price schemes rather than dynamic and complex ones (Dütschke and Paetz, 2013) and require some sort of support system to handle these decisions (Kempton and Letendre, 1997), and that electricity suppliers do not perceive as significant the demand shift to off-peak hours (Henley and Peirson, 1994). When considering these aspects, and reflecting on the extensive evidence that individual behaviour is not always rational, it is evident the need to consider psychological aspects of EV-owners facing short-term versus long-term charging decisions and interacting with the supplier that have received very limited attention in the literature, as the only considered psychological aspects concern social etiquette (Franke and Krems, 2013) and resource replenishing behaviour (Caperello et al., 2013).

This study contributes to the body-of-knowledge concerning EV charging by challenging the assumption that EV-owners are rational utility maximizers in their charging decisions and hence representing the psychological aspects that are relevant to DSM contract selection and the development of realistic agent-based and optimization models otherwise affected by the neglect of these psychological aspects. Specifically, this study proposes a novel behavioural model that represents utility maximization under myopic loss aversion (MLA) in the context of an ultimatum game (UG) between two players. The model represents the behaviour of EV-owners bargaining with the electricity supplier about the postponement of the charging time and the amount of the discount by selecting when to charge and at what price. Moreover, the model considers MLA leading individuals to be risk averse in short-term decisions and differentiates itself from the 'deadline differentiated pricing' model (e.g., Bitar and Low, 2012; Bitar and Xu, 2013; Salah and Flath, 2014) where the supplier proposes a menu of deferral options and the consumer plays a role in specifying the menu that the supplier bargains with.

The novelty of the proposed model is (i) the consideration of MLA that would induce EV-owners to propose deferral times closer to an optimal solution for long-term decisions rather than short-term ones, and (ii) the extension of the UG by recognizing that EV-owners make their decisions under risk since postponing the EV charging might translate into mobility constraints. Most relevantly, the novelty of the proposed model is not restricted to EV charging decisions: (i) while previous studies on MLA considered a single individual, this is the first model exploring MLA within a two-player UG and hence investigating MLA as related not only to the individual's gains or losses, but also to the individual's cautiousness in the proposal because of the need to consider the responder's strategy (Driesen et al., 2010); (ii) while previous studies on MLA considered only monetary decisions, this is the first model representing MLA for time-based decisions and hence looking into mental accounting for time as possibly similar to the one for money (Rajagopal and Rha, 2009).

The behavioural model is validated by three experiments within an experimental economic laboratory setting that covers three decisions within two contract durations. The three decisions concern (i) to postpone EV charging to off-peak periods for a discount proposed by the supplier, (ii) the amount of discount to request for off-peak charging at times decided by the supplier, and (iii) the amount of discount to accept for supplier-controlled charging. The two contract durations entail (i) a short-term (daily) framing and (ii) a long-term (weekly) framing, and it should be noted that alternative contract durations (e.g., daily versus monthly) would not affect the results as MLA testing is robust to different stakes and different return amounts (see, e.g., Camerer and Hogarth, 1999; Langer and Weber, 2005). The three experiments tested whether the long-term contract framing lessens MLA behaviour while controlling for possible confounding factors. In the first experiment, participants were requested to evaluate the trade-off between postponing the charging to off-peak periods and risking to experience mobility constraints for unforeseen events requiring traveling with the EV not being charged. In the second experiment, participants were requested to propose a discount for postponing the charging while still facing the possible rejection by the supplier, the occurrence of unforeseen events and the aforementioned mobility constraints. In the third experiment, partic-