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Response of electric vehicle drivers to dynamic pricing of parking and charging services: Risky choice in early reservations ☆

C. Latinopoulos *, A. Sivakumar, J.W. Polak

Department of Civil and Environmental Engineering, Imperial College London, UK

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ABSTRACT

When clusters of electric vehicles charge simultaneously in urban areas, the capacity of the power network might not be adequate to accommodate the additional electricity demand. Recent studies suggest that real-time control strategies, like dynamic pricing of electricity, can spread the demand and help operators to avoid costly infrastructure investments. To assess the effectiveness of dynamic pricing, it is necessary to understand how electric vehicle drivers respond to uncertain future prices when they charge their vehicle away from home. Even when data is available from electric vehicle trials, the lack of variability in electricity prices renders them insufficient for this analysis. We resolve this problem by designing a survey where we observe the stated preferences of the respondents for hypothetical charging services. A novel feature of this survey is its interface, which resembles an online or smartphone application for parking-and-charging reservations. The time-of-booking choices are evaluated within a risky-choice modelling framework, where expected utility and non-expected utility specifications are compared to understand how people perceive price probabilities. In the progress, we bring together theoretical frameworks of forward-looking behaviour in contexts where individuals were subject to equivalent price uncertainties. The results suggest that (a) the majority of the electric vehicle drivers are risk averse by choosing a certain price to an uncertain one and (b) there is a non-linearity in their choices, with a disproportional influence by the upper end of the price distribution. This approach gives new perspectives in the way people plan their travel activities in advance and highlights the impact of uncertainty when managing limited resources in dense urban centres. Similar surveys and analyses could provide valuable insights in a wide range of innovative mobility applications, including car-sharing, ride-sharing and on-demand services.

1. Introduction

Mobility electrification can contribute to the decarbonisation of the transport sector but at the same time it may introduce an additional burden to the power grid, especially at the distribution level (Clement-Nyns et al., 2010). Such stresses

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* Corresponding author.
E-mail addresses: charilaos.latinopoulos10@imperial.ac.uk (C. Latinopoulos), a.sivakumar@imperial.ac.uk (A. Sivakumar), j.polak@imperial.ac.uk (J.W. Polak).

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would be reduced if charging demand could be distributed smoothly in time and space. Demand management requires an intermediate agent that will function as a bridge between electricity market players and EV drivers. This aggregator, or Charging Service Provider (CSP) has to satisfy the target State Of Charge (SOC) for each EV individually and at the same time to optimize the charging activities subject to the local grid constraints (Sundström and Binding, 2011).

Fleet aggregation or smart charging is usually viewed as a service to the supplier side, whereas there is less interest for the demand side and the service proposition to the EV user. However, the Internet of Things (IoT) and the digitalization of the grid create a whole new set of opportunities for a customer-centric management of EV drivers with energy services that are tailored to personal consumption patterns (Giordano and Fulli, 2012). Similar personalization has been successfully implemented in other service industries, like e-commerce where recommender systems improve the experience of the users and yield substantial profits for the service providers (Qiu et al., 2015).

The challenge that follows this upsurge of sensing technologies and communication solutions in parking applications is how to exploit them in order to improve the level of service, optimize the utilization of resources (Zargayouna et al., 2016) and maximize the profits for the operators. One promising method in this direction is revenue management (RM).

Most of the existing studies on EV smart charging adopt standard exogenous assumptions for charging behaviour that do not correct for the endogeneity between the price of the service and charging choices. On the other hand, choice-based RM approaches, firstly introduced and theoretically developed by Talluri and van Ryzin (2004), explicitly capture the sensitivity of demand to price and other factors by using discrete choice models. Identifying heterogeneous segments of the relevant market, and calibrating the demand coefficients for these segments can significantly improve revenue performance (Garrow, 2010).

In previous work, the authors have presented a choice-based revenue management framework as an alternative approach to model charging coordination (Latinopoulos et al., 2015; Latinopoulos, 2016). The results of a microsimulation model based on this framework have shown that the net revenue for a charging service provider is higher compared to all uncontrolled scenarios and this improvement is in the range of 5–10%. The RM model depends on a reservation system, where customers have the chance to book a charging post 24 h in advance of their preferred arrival time at the parking facility.

This paper aims to unfold the behavioural process that takes place in such a reservation system and to model the response of EV drivers to dynamic pricing of parking-and-charging tariffs. Looking at different theoretical perspectives of intertemporal choices and decision-making under uncertain prices, it was found that there is a gap in the literature, especially for urban mobility problems. The suggested methodological framework addresses this gap, intending to achieve the following objectives:

- Measurement of drivers' *response to dynamic pricing* for out-of-home charging events.
- Understanding *attitudes towards risk* under different risky choice structures.

This framework heavily depends on data where the variability in electricity prices is adequate, in order to estimate the drivers' willingness to pay. However, the majority of electricity tariff programs offer either fixed or dual tariffs (i.e., differentiation between peak and off-peak overnight prices). Therefore, a secondary objective of the undertaken research is to design a survey instrument with stated choice exercises and observe how EV drivers respond to hypothetical booking scenarios.

The paper is structured as follows: Section 2 provides the context for parking-and charging pricing and reviews existing modelling approaches for behavioural response to dynamic pricing in other services, like airline tickets or residential electricity. Section 3 presents the survey and the choice experiments that have been developed in order to understand how people would respond to dynamic pricing in the context of electric mobility. In Section 4, the developed risky choice-modelling framework that captures the booking behaviour of the respondents is presented, while the results are demonstrated in Section 5. Finally, Section 6 concludes with the implications of these findings and the most promising directions for future research.

2. Background

2.1. Context of parking-and-charging pricing

Parking reservation systems are already applied in various contexts, from downtown, to airport and train station facilities. SpotHero (SpotHero, 2016), and JustPark (JustPark, 2016) are well-known real-time parking services that allow users to compare parking options and book a parking spot in advance.

Pierce and Shoup (2013) implemented a performance-based pricing technique and adjusted locational prices in order to achieve an on-street parking occupancy rate between 60% and 80% for each block in the area of interest at San Francisco, but the variation in prices is very slow. This project (SFPark) has shown the possibility of overcoming some of the political barriers to dynamic pricing policies in parking. Xerox (2016) has developed another algorithm that modifies prices according to historic data and predictions of parking demand. This algorithm has the same drawback with SFPark: it is impossible to anticipate short-term changes in demand since the prices are updated once every few weeks (Mackowski et al., 2015).