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Title **Understanding electric vehicle charging behaviour towards a demand side management for parking facilities: A stated preference analysis**

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Abstract

As the share of electric vehicles (EVs) and plugged-in hybrid vehicles (PHEVs) in the vehicle parc increases, the effect of the additional electricity demand on the power grid and particularly on the distribution level may become a concern for several stakeholders. The minimization of the negative impacts of EV-recharging can be achieved with the implementation of a demand side management (DSM) strategy. In this context, operators will be able to predict recharging loads and offer the appropriate incentives to the drivers in order to shift demand out of the peak periods. One promising method of DSM is dynamic pricing of electricity where recharging rates may fluctuate in a time-varying rationale (e.g. cheap overnight tariffs), a load-based rationale or a combination of the two. However, there are few existing analyses of consumer preferences towards these pricing regimes and those that do exist have been formulated in the context of in-home electricity consumption.

In this paper we develop a two-stage discrete choice model to understand how recharging choices, and subsequently travel choices, could be affected in response to price signals. During the ***first stage***, the daily price distribution is assumed to be predetermined and known by the EV drivers. Based on this information, they can make a reservation in advance, of a product that can be defined as a “charging bundle”. This bundle is a combination of a location, a time window and a charging speed, determined by the infrastructure available, which would accommodate the required state of charge (SOC) by the users. As a result their choice is intrinsically linked with higher level decisions, like daily activity scheduling and parking choices. On the other hand, the ***second stage*** of the model is intended to treat inter-temporal choices with respect to the uncertainty about future prices and product availability.

Applying the aforementioned framework in out-of-home charging scenarios is of great interest for several reasons. First, smart charging and coordination of EV clusters is a challenging task for public or private parking operators and for all sort of facilities that provide parking places (e.g. business fleets, supermarket lots etc.). Lack of familiarity with the new technology can complicate the management of charging stations by the operators, resulting to the emergence of intermediate agents, known as Charging Service Providers or aggregators. These agents would have to optimally allocate the available power to satisfy recharging demand and at the same time maximize revenue for the concerned operators. Therefore, their role would be facilitated by a better understanding of the spatiotemporal distribution of electro-mobility and its underlying choice mechanisms.

Second, despite the indications from existing EV trials that most of the charging activities are taking place at home, it is vital to invest in the development of public infrastructure to tackle “range anxiety” and encourage early adoption of the vehicles. Moreover, considering the case of densely populated urban areas, it is a reasonable assumption that many of the potential EV owners won’t have access to private off-street parking places and thus charging opportunities at home.

One of the prerequisites of our modelling approach is the existence of a reservation system where customers would be able to book in advance the "charging bundle" of their preference. The benefits from pre-booking can be multidimensional, discharging both the transport and the power network. Parking-search times can be eliminated, thus relieving traffic congestion and reducing emission concentrations, while energy use predictions can be enhanced, allowing for better coordination of supply and demand and for better integration of renewable sources to the grid.

Methodologically, in the first stage we estimate a latent class multinomial logit model to capture heterogeneity in charging choices under a dynamic pricing component that reflects the systematic variation of time-of-day demand. Moving to the second stage, this systematic term is complemented by a non-systematic component that reflects the load from the incoming reservations during the booking horizon. Forward-looking (or strategic) behaviour is investigated through a binary choice of whether to buy a specific bundle now or wait for a future price drop due to unrealized demand. The cognitive process described above has strong similarities with the case of online search for an airplane ticket or a hotel room. The probabilistic nature of the waiting alternative turns this choice into a risky one, though, we do not try to understand how people form beliefs about future prices before they decide to purchase or to postpone. Instead we focus on the decision itself and we assume that they have certain knowledge of the future distribution based on previous observations.

One of the main issues in the EV research field is the difficulty in obtaining calibration data, due to currently low levels of EV market penetration. An increasing number of trials and demonstration projects have analysed every-day movements and recharging profiles of EV users combining in-vehicle and charging post loggers. However, the variability in these trials is not sufficient to explain charging behaviour under different recharging rates, spatial attributes and most importantly, dynamic pricing scenarios. For this reason, we have developed a stated preference instrument for out-of-home charging choices, which enables our model estimation and is going to be administered to experienced EV drivers in the city of London.

The outline of this paper is as follows: First we underline the motivations for exploring operational models for charging facility owners and/or charging service providers. The significance of integrating explicit demand modelling techniques with these control processes is highlighted. Thereafter, we present our methodological approach for the analysis of the charging behaviour for out-of-home activities and we illustrate the design of the SP survey that we will employ for data collection. At the moment, the development of the online survey tool is at its final stage and it is soon going to be tested in a pilot phase. We will conclude with the demonstration of results from this first wave of respondents (e.g. price sensitivities, temporal preferences, model fit etc.) along with some insights regarding their personal experiences, the level of complexity and the method of administration.