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Fast charging stations: Simulating entry and location in a game of strategic interaction☆

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ABSTRACT

This paper uses a game of strategic interaction to simulate entry and location of fast charging stations for electric vehicles. It evaluates the equilibria obtained in terms of social welfare and firm spatial differentiation. Using Barcelona mobility survey, demographic data and the street graph we find that only at an electric vehicle penetration rate above 3% does a dense network of stations appear as the equilibrium outcome of a market with no fiscal transfers. We also find that price competition drives location differentiation measured not only in Euclidean distances but also in consumer travel distances.

1. Introduction

The reduction of carbon dioxide emissions has been one of the main objectives of various United Nations' summits with the intention of moderating or reversing climate change. The focus has fallen on the road transport sector, which contributes more than any other industry to the volume of emissions. Indeed, according to the latest statistics published by the European Union, the sector's share in total emissions in 2010 was as high as 19.98%.

While electric vehicles are not zero-emissions, given that electricity has to be generated to power them, a number of studies, including Ahman (2001) and WWF (2008), show that electric vehicles are more efficient, generating lower emissions per kilometer. This reduction is even higher in countries with a mix of electricity generation sources, that is, with a higher share of renewables, whether hydro, wind or solar power.

While the introduction of electric vehicles should play a key role in reducing road transport emissions, their eventual adoption must first overcome a host of barriers. One barrier is the purchase cost associated to electric vehicles (EV) and the willingness to pay from consumers. In this sense, different studies analyze the effect of price over adoption (Larson et al., 2014) and the willingness to

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pay with or without public subsidies (Helveston et al. 2015 and Parsons et al. 2014) or the effect of public subsidies over EV adoption (Jenn et al., 2013).

Another of the key barriers is the limited number of charging stations that generate 'range anxiety' among users of electric vehicles, fearful of not reaching their destination. In this regard, the deployment of a network of fast charging stations that can reduce this anxiety is essential to the adoption *en masse* of electric vehicles[1].

This paper uses a game of strategic interaction to simulate the entry of fast charging stations for electric vehicles. The study evaluates the equilibria in terms of social welfare and firm space differentiation. Demand specification considers consumer mobility. Decisions of consumers and producers are modelled taking into account the expectation of finding a given facility located in each feasible location. The model is applied to the case of the city of Barcelona using the mobility survey, demographic and income data, and the street graph of the city.

To the best of our knowledge, this is the first paper to study the entry and location of fast charging stations using a simulated game of competitive strategic interaction among potential entrants. By so doing, we seek to offer novel perspectives on the following two questions. First, the simulations identify the penetration rate of electric vehicles necessary to have a profitable fast charge station network (without fiscal transfers), and a network that can overcome commuters 'range anxiety' . Second, the model allows us to assess whether competing firms tend to cluster or disperse when consumers move around commuting routes. Differentiation is measured in terms of consumer deviations from the commuting paths to the facilities, rather than distances from a given fixed consumer location to facilities.

With respect to the first question, we calculate that the threshold for the penetration of electric vehicles would have to reach 3% to guarantee the sustainability of the fast charge station network in Barcelona. This threshold allows commuters to recharge close to 10% of their energy requirements on the go, and overcome their 'range anxiety'. This threshold is around 15 times higher than the current penetration rate[2]. With respect to the second issue, we find evidence that price competition drives location differentiation. Price competition leads firms to locate farther away from competitors measured in deviations from commuting paths. Clustering is not an issue in this new industry. These results are novel but similar to the results obtained by the traditional models of space differentiation that measures how firms locate farther apart in distances with respect to consumer fixed locations.

Following on from this introduction, the rest of the paper is organized as follows. In Section 2 we present the literature related to this paper on spatial localization of firms. In Section 3, we describe the set-up of the game of strategic interaction used in simulating entry at the different locations. In Section 4 we present our data and empirical methodology. Section 5 reports the results obtained in the simulation for the city of Barcelona and the robustness checks, and finally the paper ends by discussing the main conclusions arising from the simulation.

2. Literature review

There are two forces acting behind firm location decisions known in the economic literature as 'the market power effect' and the 'business stealing effect' . The 'market power effect' is known as the capability of firms to set differentiated prices from competitors when situated farther apart from them. Distance increases the flexibility in the price-setting decision of firms and, therefore, offers incentives to locate far apart from competitors. The 'business stealing effect' , on the other hand, offers the opposite incentive. Being close to a competitor increases the probability of stealing some market share. If 'business stealing effect' dominates the 'market power effect', agglomeration of firms is expected.

Previous theoretical studies examining the spatial localization of firms do not report a unique outcome in their predictions as to whether entrants locate in close proximity to incumbents or at some distance from them. Results depend on the assumptions made over consumer preferences and costs, the type of competition examined and the number of competitors in the market. Indeed, a great effort has been devoted in the economic literature to study the spatial competition among firms since the seminal studies of Hotelling (1929) and D'Aspremont and Thisse (1979) that report opposing outcomes of minimum and maximum differentiation, respectively, in a setting with two players. These opposite results are due to the different assumptions regarding consumer transportation cost: while Hotelling (1929) considers lineal transport costs, D'Aspremont and Thisse (1979) introduce transport costs in a quadratic form. Hotelling (1929), however, does not find a unique stable equilibrium when more than two entrants are taken into account. Indeed, closer to our paper are the studies examining competition in both price and location in an oligopoly. In particular, in a setting with heterogeneous consumers Anderson et al. (1992) predict that the agglomeration of firms is the most probable outcome. In this setting, differentiation in pricing implies a differentiation in locations in contrast to uniform price setting that leads towards clustering in locations.

In the empirical literature, clustering outcome tends to dominate; although there is evidence of both outcomes.

Early empirical studies that show clustering include the examination by Borenstein and Netz (1999) and Salvanes et al. (2005) of spatial competition in airline departure times for United States and Norway, respectively. The first authors find that when prices are fixed exogenously airlines tend to schedule departure times next to the others or, equivalently, cluster. No competing in pricing seems to drive clustering in departure times. For the unregulated period, however, results are not conclusive. Salvanes et al.'s (2005) main finding is that competitors tend to cluster when prices are set endogenously, in the case of duopoly routes compared to monopoly routes. With price competition, oligopolies seem to offer more clustered frequencies rather than monopolies.

Pinske and Slade (1998) and Netz and Taylor (2002) study the case of gasoline retail markets. The first ones focus in studying whether firms with similar contractual agreement tend to cluster or to differentiate. Using only data of the gasoline stations integrated with the four existent oil companies, the authors find that firms with equal contracts tend to cluster. The hypothesis of clustering among firms is obtained also in Vitorino (2012) analysis about shopping centers stores in the United States. Other papers such as Buenstorf and Klepper (2010) and Pennerstorfer and Weiss (2013) also find some sort of clustering.

On the contrary, spatial differentiation is also found in otherpapers. Of particular relevance for our analysis, the study of Netz and Taylor (2002) reports by focusing in Los Angeles market, that when localized in a more competitive market, gasoline stations tend to spatially differentiated from each other.

Spatial differentiation across firms is also found as a result in Seim (2006) with respect to video retail industry and in Borrell and Fernandez-Villadangos (2011) for the case of pharmacies.

Finally, Elizalde (2013) finds an inverse relationship between differentiation in multiple dimensions: geographical location and product variety. In the case of the Spanish movie theatre exhibition market, he finds that clustering in location drives differentiation in

[1] A charging station is named fast when the power is of 43 kw or more, which can recharge more than 80% of the battery in less of 30 min. The alternative technologies to recharge the car are: accelerated points (between 7 and 22 kw) that need between 1 and 4 h; and the conventional points (3 kw) that spend 8 h. We do not consider those alternatives.

[2] The current penetration rate in Spain is 0.2%, according to the International Energy Agency (2015).