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 for simulating entry of fast charging stations for electric vehicles. The paper compares the multiple equilibria obtained in terms of social welfare. Demand specification considers mobility of consumers. Decisions of consumers and producers are modelled taking into account the expected probability of finding a given facility located in each feasible location. The model is simulated using the the case of the city of Barcelona using the mobility survey, demographic and income data, and the street graph of the city. For a penetration rate of electric vehicles at 5 percent, a network of fast charging stations is self-sustainable in the case of study. Free market can lead to both an excess or insufficient entrance. Business stealing effect does not play an important role as stations cluster together around the denser traffic paths.

JEL Classification number: L13, L43, R53
Keywords: Regional Planning, Electric Vehicle; Fast Charging; Games of Strategic Interaction; Entry Models

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1 Introduction

Reduction of carbon dioxide emissions is one of the main objectives of various United Nations (UN) summits with the intention of moderating or reversing climate change. The road transport industry contributes, above any other industry, to the volume of emissions.

According to the latest statistics published by the European Union, the share of road transport emission out of the total in 2010 was as large as 19.98 percent. The European Commission planned in 2009 to decarbonise road transport in Europe in the following 5 years. There are many measures that can be implemented to decarbonise road transport as improving the efficiency of internal combustion engines, increase fuel taxes to reduce consumption, increase the use of bio-fuels, etc. Among all these feasible policies, the introduction and proliferation of electric vehicles is one of the policies that can help most to reduce emission levels.

Truly, electric vehicles do not generate global zero emissions, and one should take into account that there are emissions produced in generating the electricity to fed the vehicles. However, there are some papers (Ahman 2001, or WWF 2008) that show that electric vehicles are more efficient: those vehicles generate less emissions per kilometer. This reduction in emission levels are still higher in those countries with a mix of electricity generation that have a higher share of renewals whether hydro, wind or solar.

While the introduction of electric vehicles can play an important role in reducing emissions of road transport, the introduction and adoption of electric vehicles must overcome a host of barriers. Following the report by Analysis (2009) the four major uncertainties that could limit the introduction of electric vehicles are the following: the high cost of production of electric vehicles due to the high cost of batteries; the shortsighted of consumers that are not willing to pay more upfront for the vehicle in exchange for paying less for fuel latter on; the evolution of other technologies such as internal combustion vehicle itself that can make electric vehicles less competitive; and finally, the deployment of a charging network that limits "range anxiety" that users of electric vehicles may suffer.

We define "range anxiety" as the fear that electric vehicle owners may suffer as they may be afraid that they will not find a convenient charging point on the road if needed. The deployment of a network of fast charging stations that reduces "range anxiety" is essential to the adoption en masse of this type of vehicles.

This paper uses a game of strategic interaction for simulating entry of fast charging stations for electric vehicles. The study compares the welfare achieved in the multiple equilibria obtained. Demand specification considers mobility of consumers. 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.

As far as we know, this is the first paper that studies entry and location of fast charging stations using a simulated game of competitive strategic interaction among potential entrants. By doing this, we intend to offer novel perspectives regarding the following issues. In first place, the simulations will let us see whether it is profitable and self-sustainable a network of fast charge stations in the city. In second place, it will let us see whether firms tend to cluster or to spatially differentiate from their competitors in a free market environment.In third place, it will show us whether free market leads to an efficient number of entrants in terms of social welfare.

Previous works related to this paper are those about the number of entrants and spatial localization of firms. Both, theoretical and empirical contributions, predict that unregulated markets may deliver an inefficient number of entrants (see the following theoretical contributions, Chamberlin 1933; Suzuma and Kiyono 1986; and, Mankiw and Whinston 1986); however, within empirical approaches there's not consensus regarding the effect of the inefficiency: some found excess of entry (Berry and Waldfogel 1999; Davis 2002)while others find that free entry leads to an insufficient number of firms in the market (Gowrisankaran and Krainer 2006).

Respect to spatial localization, theory gives an ambiguous result when predicting whether entrants would localize near or far from incumbents. In this sense, seminal works of Hotelling (1929) and D'Aspremont and Thisse (1979) gives the opposite outcome of minimum and maximum differentiation, respectively. However, according to Irmen and Thisse (1998), theoretical literature is more supportive of differentiation rather than clustering. On the opposite side, in the empirical literature clustering tends to dominate, even though there is evidence for both. Furthermore, according to Netz and Taylor (2002) any equilibrium configuration can be obtained depending on the assumptions of the model, including the extremes of minimum and maximum differentiation. Empirical previous literature is given by the works of Borenstein and Netz (1999) and Salvanes et al. (2005) for the spatial competition in departures times in airlines; Pinske and Slade (1998) and Netz and Taylor (2002) for gasoline retail markets; Seim (2004) respect to video retail industry; Borrell and Fernandez-Villadangos (2011) for the case of pharmacies; and, Vitorino (2011) for shopping centers stores.

We have been able to identify a set of multiple equilibria in the free entry of strategic interaction game using the data for Barcelona. Simulations show that traffic flows, jointly with entry costs, and attractiveness of each location for the demand are driving entry probabilities of fast charging stations. We have also been able to compute welfare in the different equilibria of the game. Differences in welfare among equilibria are quite low, but both an excess or insufficient entry equilibria may be the outcome of the game.

After this introduction, the paper is organized as follows. In Section 2, we describe the set up of the entry game of strategic interaction that we are going to use to simulate entry in the different locations, and then we turn to detail the data and empirical methodology in section 3. Section 4, shows the results obtained in the simulation for the case of Barcelona city. Section 5 contains the robustness checks and policy analysis, and finally the paper ends discussing the main conclusions that can be drawn from the simulation.

2 The entry game of strategic interaction

Consider a model of entry where the geographical space is divided into a set of finite origin destination zones l $(l = 1, 2, ..., L)$ connected through a road network. Consider also that the intersection points of the road network constitute the set of finite feasible locations j $(j = 1, 2, ..., J)$ where the firms might decide to enter.

Each location is differentiated regarding two features that are common knowledge for the firms. On the one hand, the locations are differentiated regarding the set up costs of the stations, mostly the costs of grid reinforcement, outlined in the vector z_j^r, and the cost of localization, expressed in the vector l_j . On the other hand, each feasible location is considered to be attractive for consumers if it has some amenity around the area such as a coffee shop, supermarket, car wash services, etc. as detailed in the vector x_j^r.

Differently from common entry games and following Houde (2012), we assume that demand is not fixed at a single area but mobility of consumers between origin and destination zones is taken into account. We also take into account that consumers differ with respect to income(Berry, Levinsohn, and Pakes 1995).

Additionally, we consider an identically and independently distributed (*i.i.d.*) random draw that constitutes profit relevant information on costs over all feasible locations $(s_\varepsilon \epsilon_j)$ for any feasible location j $(j = 1, 2, ..., J)$. Also, we consider idiosyncratic tastes of consumers regarding the utility for individual i $(i = 1, 2, I)$ traveling along the origin and destination couple l to purchase from a facility located in j (ε_{ijl}) to be identically and independently distributed (*i.i.d*). Both random shocks are private information: the former is private information for consumers preferences when deciding where to recharge batteries on the go, and the latter is private information of costs for each potential entrant in each location (for the justification of the unobservable shock on costs see Gowrisankaran and Krainer (2006)).

Firms take observable information to estimate the expected profits of entering to each feasible location j and simultaneously decided the probability of entrance at each feasible location σ_j. The sum of probabilities of entry into the market is then given by:

$$N = \sum_{j=1}^{J} \sigma_j \tag{1}$$

We assume that there is one and only one potential entrant at each node, and that they are one-shop stations. We plan to check for robustness of the simulation when allowing for networks of stations in the strategic interaction entry game in the future.

2.1 Demand specification

Let the demand for fast charging of electric vehicles be modeled as a discrete choice problem over $j = 0, 1, 2, 3, ..., J$ possibilities. Consumers are therefore able to choose between consuming at one of the J feasible locations or recharging at home (outside-good, $j = 0$).

Let the commuting paths of individuals between origin-destination zones be called (o_l, d_l)

Additionally, let the utility of buying from store $j = 1, 2, ..., J$ depend on the distance between commuting paths of the individuals and location j, features of the location, characteristics of individuals and unobservable idiosyncratic tastes over each j location.

Then, the deterministic component of the indirect utility of buying from store j to individual i that makes trip l (ϕ_{ijl}) can be expressed as the following:

$$\phi_{ijl} = \lambda D_i[(o_l, d_l), l_j] + \sum_{r=1}^{R} \beta_r x_{jr} + (\overline{\alpha} + \alpha \log Y_i) p_j \tag{2}$$

Being the indirect utility function of recharging at any of the feasible locations j:

$$u_{ijl} = \phi_{ijl} + \varepsilon_{ijl} \tag{3}$$

And the indirect utility function of recharging at home:

$$u_{i0l} = 0 + \varepsilon_{i0l} \tag{4}$$

where $D_i[(o_l, d_l), l_j]$ represents the distance between path (o_l, d_l) and facility j and λ is a parameter that express the disutility of deviating from the commuting path to reach the facility j measured in minutes; x_{jr} is a binary variable that takes the value of 1 whenever at the feasible location j there are amenities such as car wash services, supermarkets or coffee stores; $\overline{\alpha} p_j$ measures the desutility of paying posted prices; and $\alpha \log(Y_i) p_j$ introduce the interaction between income and prices and express the differentiation between individuals that make the same trip regarding the price sensitivity for different levels of personal income.

As usual in multinomial logit models, the utility of recharging at home is normalized to zero.

Thus, the probability for individual i that makes trip l to recharge at facility j, Φ_{ijl} is given by a multinomial logit model where the individual is allowed to choose between buying at any facility $j = 1, 2, ..., J$, recharging at home $j = 0$, or buying from any other localization. However, as we focus in an utility model in which each consumer and potential entrant does not know where will be stations available, following Bajari and Nekipelov (2010) and Borrell and Casso (2011) we allow consumers to evaluate utility of recharging in each node with respect to the utility of recharging in any other node under the expectation of the probability that finally a station would be available in those other nodes. This is why the existence of a facility in any other location apart from j enters in expected terms as the probability for individual i that makes trip l of finding a facility in any other location. This probability of having any entrant at each location is named by the parameter σ_k. Consumers form their expectation of σ_k all simultaneously, as an assumption for tractability.

Φ_{ijl} is therefore given by:

$$\Phi_{ijl} = \frac{\exp[\phi_{ijl}]}{1 + \exp[\phi_{ijl}] + \sum_{k=1}^{J} \sigma_k \exp[\phi_{ijl}]} \tag{5}$$

And the probability for the outside good is given by:

$$\Phi_{i0l} = \frac{1}{1 + \sum_{j=1}^{J} \sigma_k \exp[\phi_{ijl}]} \tag{6}$$

On the other hand, we assume that individuals demand heterogeneous quantities of energy proportional to the distance travelled per year, which is obtained by adding all the trips between origin destination zones l as registered in the survey for each individual i, multiplied by the number of days in a week and the number of weeks within a year: $\sum_{l=1}^{L} D(o_l, d_l)$.

Also, we consider that the quantity of energy demanded depends on the share of the electric vehicle (υ). It also depends on the share of consumption of the electric vehicle recharged on the go (τ), and the energy consumption per kilometre (C_0). We assume that all these parameters are common for all individuals. Therefore, individual demand for energy on the go is given by:

$$q_i = \upsilon \tau C_0 \sum_{l=1}^{L} D(o_l, d_l) \tag{7}$$

2.2 The supply

Given the previous set up, expected sales at location j are given by integrating by simulation across consumers the probability of recharging at each location j:

$$s_j = \sum_{i=1}^{I} p_j \Phi_{ijl} q_i \tag{8}$$

And expect profits are therefore the following:

$$\pi_j = s_j - \sum_{i=1}^{I} c_j \Phi_{ijl} q_i - F_j \tag{9}$$

where c_j are variable costs of providing energy that is common to all locations, and F_j is the fixed cost associated to the location j.

Let the fixed cost F_j have an observable part composed by a common component in equipment for all locations c, specifics component to each location j regarding grid reinforcement z_j and localization l_j, and the unobservable ($i.i.d.$) random draw on costs ($s_\varepsilon \epsilon_j$). Therefore, the fixed cost equation is given by:

$$F_j = c + \mu_j z_j + l_j + s_\varepsilon \epsilon_j \tag{10}$$

where μ_j is a parameter that takes three different values according to index variable z_j

2.3 Solving the entry game of strategic interaction

We assume that each entrant compete a la Bertrand in prices with respect to the set of expected entrants that are differentiated by location. From the system of first order conditions, the Nash equilibrium pricing is the following:

$$p_j = c_j - \frac{\sum_{i=1}^{I} \Phi_{ijl} q_i}{\sum_{i=1}^{I} \frac{\partial \Phi_{ijl}}{\partial p_j} q_i} \tag{11}$$

where $\frac{\sum_{i=1}^{I} \Phi_{ijl} q_i}{\sum_{i=1}^{I} \frac{\partial \Phi_{ijl}}{\partial p_j} q_i}$ is the mark up of the firm that enters at location j.

Consider now that from Bertrand competition an equilibrium price is obtained. Finally, suppose that given equilibrium pricing p_j and expected profits in each feasible location π_j, each potential firm at each node decides simultaneously to enter or not to enter. As we assume that the unobserved costs distribute as an type-1 extreme value random shock, the probability of entry is given by the following logit model:

$$\sigma_j = \frac{\exp[E(\pi_j)]}{1 + \exp[E(\pi_j)]} \tag{12}$$

Straightforward, the result of the game of strategic interaction gives the total probability of entrance to the market N:

$$N = \sum_{j=1}^{J} \sigma_j \tag{13}$$

Regarding equilibrium, the type-1 extreme value distribution of the error term guarantees that firms conjectures are monotonic, continuous and strictly bounded inside the set (0,1). Therefore, by Brower's fixed point theorem the entry game of strategic interaction has at least one solution.

3 Data and methodology

We use the case of Barcelona as a case-study to test how the free entry game of strategic interaction simulates entry and location of fast charging stations in a dense city for which we have mobility survey data, and also demographics and income information, under some assumptions on the values of some parameters such as the percentage of electric vehicles out of the total number of vehicles in the city.

The origin-destination paths. The origin-destination commuting paths were built using three sources of information: the Mobility Survey from the Metropolitan Transport Authority and the Territory Department for the year 2006 and, the Catalonia Roads Graph and the Neighborhoods of Barcelona Map published by the Regional Government.

In the survey, the Metropolitan Area of Barcelona is segmented in 308 zones, 63 of which correspond to the city of Barcelona. The data corresponding to trips made of residents of the Metropolitan Area in private vehicle inter-zona arrive to 58,443. From them, 18,411 have origin or destination Barcelona and 6,330 are made inside the city. Taking into account the commuters, the most frequent origin destination zone is 17, the south entrance to the city, while only considering the trips within the city the mode is zone number 12, in the city centre.

The Catalonia Roads Graph was filtered leaving the information of the city, and 4 nodes and 2 arcs were added using the map of the city published online at the web of the Government of Barcelona. In total, the road graph used contains 891 nodes and 2552 arcs. These arcs were made bidirectional, as the work already uses a simplified version of the network within the city.

The Neighborhoods of Barcelona Map segments the city in 73 neighborhoods. It provides information regarding population disaggregated by gender and area of each of the neighborhoods. Total population arise to 1,631,259 inhabitants, with a density per neighborhood in between 0.1 and 5.99 percent.

In order to estimate the corresponding shortest path for the trips within the city, three step methodology was used: first, each origin and destination zone was assigned to a node of the network by first building the geometric centroids and then assigning them to the correspondent node with population density criterium.In second place, spatial correlation intra-origins and intra-destinations was tested and kriging techniques were applied. With the use of kriging and the density of population correspondent to each node, we were capable to assign a probability of being an origin or a destination to all the nodes in the network. Finally, a random sample with uniform distribution was built for every origin and every destination of the paths in order to assign the nodes correspondent to each commuting path within the survey.

The commuters were assigned to the correspondent node of entry into or exit out of the city according to the shortest path given by googlemaps.

For estimating the commuting path between every origin-destination zone Dijkstra shortest paths algorithm were used (Dikstra 1959). We end up having the flows of mobility through the 891 nodes and 2552 arcs across the city of Barcelona.

With all this information, we were able to have an plausible approximation to the flows of mobility in the city for all types of movements: home to work, home to study, home to shopping, home to any other destination, all back to home movements, and pair movements among all these destinations across the 891 nodes and 2552 arcs.

The feasible locations. The nodes are differentiated regarding set-up costs and attractiveness for the demand. For that purpose, in first place a map with all fuel stations, hypermarkets and malls of the city was built and the facilities were assigned to the closest node of the net. In second place, the nodes of the net were assigned to one of the 73 neighborhoods of Barcelona.

Regarding set-up costs, locations were aggregated into three categories according to the following criteria (Figure 1): the nodes in which there is already a petrol station with car wash; the nodes with a petrol station with more than 10 pumps; and neither of the previous options. Entrants in most of the nodes should pay full upfront set-up costs of grid reinforcement as there is neither a petrol station with car wash, neither a petrol station with ten pumps. All facilities must pay the localization cost corresponding to the rent of a commercial establishment in the correspondent neighborhood were are located. Set up costs range from 57,676 to 1,236 .

The data regarding petrol stations was quoted on−line from the Spanish Ministry of Industry, Tourism and Commerce; the costs of connection were taken from Schroeder and Traber 2012 the costs of localization in Barcelona were assigned according to 2007 average prices of the squared metre for commercial establishments published by Barcelona Open Data.

The malls and hypermarkets (Figure 1) jointly with the amenities of the petrol stations were used to characterize the feasible locations regarding its attractiveness for the demand. The feature was included by the use of a binary variable that took value 1 whenever at the

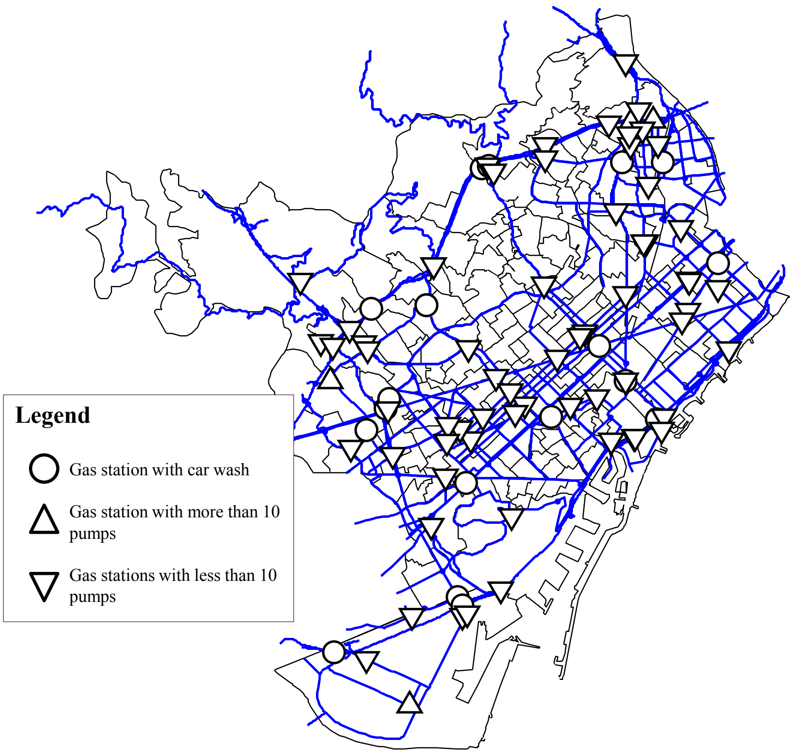

Figure 1: Current location of fuel stations, hypermarkets and malls in Barcelona used for defining fast charging installation costs and demand drivers in the feasible locations j

feasible location amenities such as bar, restaurant, store, and so on were available.

Regarding the marginal cost of providing energy, it was considered for every feasible location equal to 0.15 euros/kwh applied to a standard recharging of 16 kwh.

Assumptions on consumers and mobility. Consumers considered were all making trips in private vehicle between zones within the city and the commuting trips to Barcelona from the rest of Catalonia.

An homogeneous penetration of electric vehicles in each zone of Barcelona was considered.

Income data for residents of the city was taken from a report on income distribution in the city made by the Barcelona City Government and the Catalan Statistics Institute (IDESCAT), income correspondent to commuters residents of the Metropolitan Area was taken from the Diputation of Barcelona statistitcs, and, for the residents of the rest Catalonia income data from the Catalan Statistics Institute (IDESCAT)was used. The average income for the individuals of the sample takes a value of 16,439.41 , with a standard deviation of 5,600.26 , being the maximum income of 33,809 and the minimum of 10,276 .

The parameters. The equilibrium at the entry game of strategic interaction was solved given the parameters of the indirect utility function: $\lambda, \beta, \overline{\alpha}, \alpha$ and given μ_j for the grid reinforcement costs.

From them, λ was taken from Houde (2012), as it is the only paper which includes the disutility of deviating from the commuting path for the estimation of demand of gasoline considering consumers mobility.

β was set-up at 2.5, as the existence of amenities constitutes a fundamental characteristic at the moment of choosing whether the location to recharge or recharging at home when taking into account that the average time for a recharge it is of 20 minutes. Robustness checks are pending.

Regarding price elasticity, $\overline{\alpha}$ was set-up at -0.65 and α at 0.06.

Different measures were used in order to test the economic consistency of the parameters. In first place, it was calculated the travel cost as done in Houde (2012): taking the rent Y to rent per minutes and in cents of euros, the travel cost is given by $\frac{\lambda}{\overline{\alpha}+\alpha * log(Y)}$. The result show a need of 1.7119 cents difference in price in order to deviate one minute from the commuting path. Therefore, given an average recharge of 16 kwh, it implies a compensated cost for deviating to do an average recharge of 16.43 euros per hour. If we compare this amount with the average income per hour of 13.07 euros published by the IDESCAT for Catalonia for the year 2006, we get a really close result.

In second place, the price elasticity of a charge in a location j respect to the other locations and the outside good was obtained from:

$$\varepsilon_{pj} = \frac{\partial \Phi_{ijl}}{\partial p_j} q_i \frac{p_j}{\Phi_{ijl} q_i}$$

with ε_{pj} the price elasticity for location j; giving an average result of a 1.6 percent decrement in quantity sold in location j for $j = 1, ..., J$ because of an increment in price of a 1 percent. From that amount, a percentage goes to the outside good and another to recharges at home. This last elasticity was also calculated as:

$$\varepsilon_{p0} = \frac{\partial \Phi_{iol}}{\partial p_j} q_i \frac{p_j}{\Phi_{i0l} q_i}$$

giving a result of -0.3731 percent increment in the recharges at home for an increment in the price of fast the fast charges in 1 percent. This data is consistent with price elasticities of the demand of petrol for Spain published by CEPAL.

Finally, μ_j takes the value of 0 whenever at the feasible location there is a petrol station with car wash, 1,019 euros a year whenever at the location is a petrol station with 10 or more pumps, and, 2,038 euros a year when the location does not has any of the mentioned facilities. The results come from considering an annual payment with a rate interest of 6 percent for a credit in ten years for grid reinforcement costs.

Additional robustness checks of the parameters will be made in the future.

Methodology. To avoid the curse of dimensionality, we integrate logit demand across a random sample of only 100 representative individuals. They were selected from the mobility survey sample according to the weight of the interviewed sample with respect to the total population.

The probability of entering at each location was obtained through a simulation process including the simultaneous determination of: i) the probability for origin-destination trip i to refuel at facility j (Φ_{ijl}); ii) the Bertrand (Nash in prices) equilibrium pricing at each feasible location j (p_j); and, iii) the probability of entry to location j (σ_j).

The probability for origin-destination trip l of individual i to refuel at facility j (Φ_{ijl}) was introduced as a multinomial logit with random coefficients as in Berry et al. (1995). The sources of heterogeneity are two: i) origin-destination path (o_l, d_l); and ii) income Y_i.

The price equation p_j was derived from the first order condition of the firms by considering Bertrand competition (Nash in prices equilibrium). See also Berry et al. (1995).

Finally, the probability of entry to location j (σ_j) was introduced as a discrete choice logit model where, following Borrell and Casso (2011), the expected profits of a potential entrant in each location j depends on the probability of having any number of competitors in the others $j-1$ feasible locations.

The simultaneous non-linear entry game problem was solved in Matlab by iteration.

To search for multiple equilibria we used a three step methodology: first, we obtained the vector of entry probabilities in equilibrium starting iterations with $\sigma_1 = ... = \sigma_k = ... = \sigma_J = 1$ as if consumers were expecting to find a fast charging station in all nodes and entrants expect to have a competitor in all other nodes, and the vector of entry probabilities in equilibrium starting iterations with $\sigma_1 = ... = \sigma_k = ... = \sigma_J = 0$ as if consumers were expecting to find only one fast charging station and entrants at each node expect to be monopolists, and we run the entry game from both extreme solutions to look for the equilibria; in a second step we obtained the vector of entry probabilities in other equilibria starting iterations using the entry probabilities obtained in the range of the previous two equilibria with the smallest and the largest number of entrants.Finally, we obtained the vector of entry probabilities in other equilibria starting iterations using entry probabilities in the middle of the equilibria obtained in step two.

We estimated welfare as the sum of the producer and consumer surplus. In order to add the utility of the different individuals i of recharging in every feasible location j the function developed in equations 1 and 2 was normalized by dividing every coefficient by $-(\overline{\alpha}+\alpha\log\overline{Y})$ to take every component to monetary terms. The normalized indirect utility is therefore given by:

Being the indirect utility function of recharging at any of the feasible locations j:

$$u_{ijl} = \lambda' D_i[(o_l, d_l), l_j] + \sum_{r=1}^{R} \beta_r' x_{jr} + (\overline{\alpha}' + \alpha' \log Y)p_j + \varepsilon_{ijl}' \tag{15}$$

with $\lambda' = \frac{\lambda}{(\overline{\alpha}+\alpha\log\overline{Y})}$; $\beta_r' = \frac{\beta_r}{(\overline{\alpha}+\alpha\log\overline{Y})}$; $\overline{\alpha}' = \frac{\overline{\alpha}}{(\overline{\alpha}+\alpha\log\overline{Y})}$; $\alpha' = \frac{\alpha}{(\overline{\alpha}+\alpha\log\overline{Y})}$ and, $\varepsilon_{ijl}' = \frac{\varepsilon_{ijl}}{(\overline{\alpha}+\alpha\log\overline{Y})}$.

4 Results

The model of strategic interaction has multiple equilibria. However, we have been able to identify that equilibria is always located in between a subset of the following expected number of entrants: [327.23,345.9]. Starting iterations with $\sigma_1 = ... = \sigma_k = ... = \sigma_J = 1$ as if consumers were expecting to find a fast charging station in all nodes and entrants expect to have a competitor in all other nodes renders always a unique equilibrium with the expected number of entrants equal to 327.23. Starting the iterations assuming that $\sigma_1 = ... = \sigma_k = ... = \sigma_J = 0$ as if consumers were expecting to find only one fast charging station and entrants

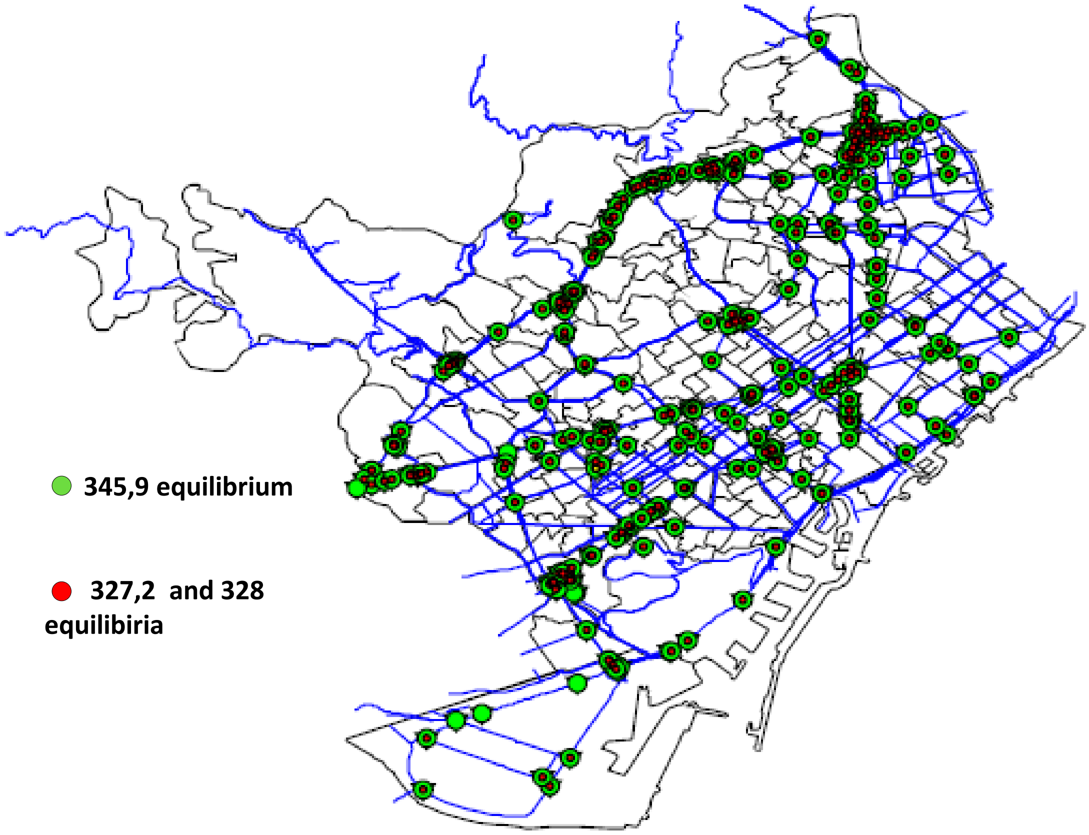

Figure 2: Multiple equilibria obtained

at each node expect to be monopolists, we always end up in the equilibrium with the expected number of entrants being equal to 345.9.

In between these range, we have identified some other equilibrium such as the one with the expected number of entrants equal to 328 fast charging station (Figure 2). Expected profits seem to depend on both traffic flows, entry costs and demand attractiveness as non of them separately seem to be determinant to locate a fast charging station.

Among these three equilibria identified, welfare is maximized in the equilibrium with a expected number of entrants equal to 328, with smallest profits and largest utility (Figure 3). The second equilibrium in terms of welfare is the one with 345.9, and the last corresponds to the 327.2, with lowest utility and highest profits. Achieving the 327.2 equilibrium implies a 12.5 percent lost of welfare respect the equilibrium with the highest welfare.

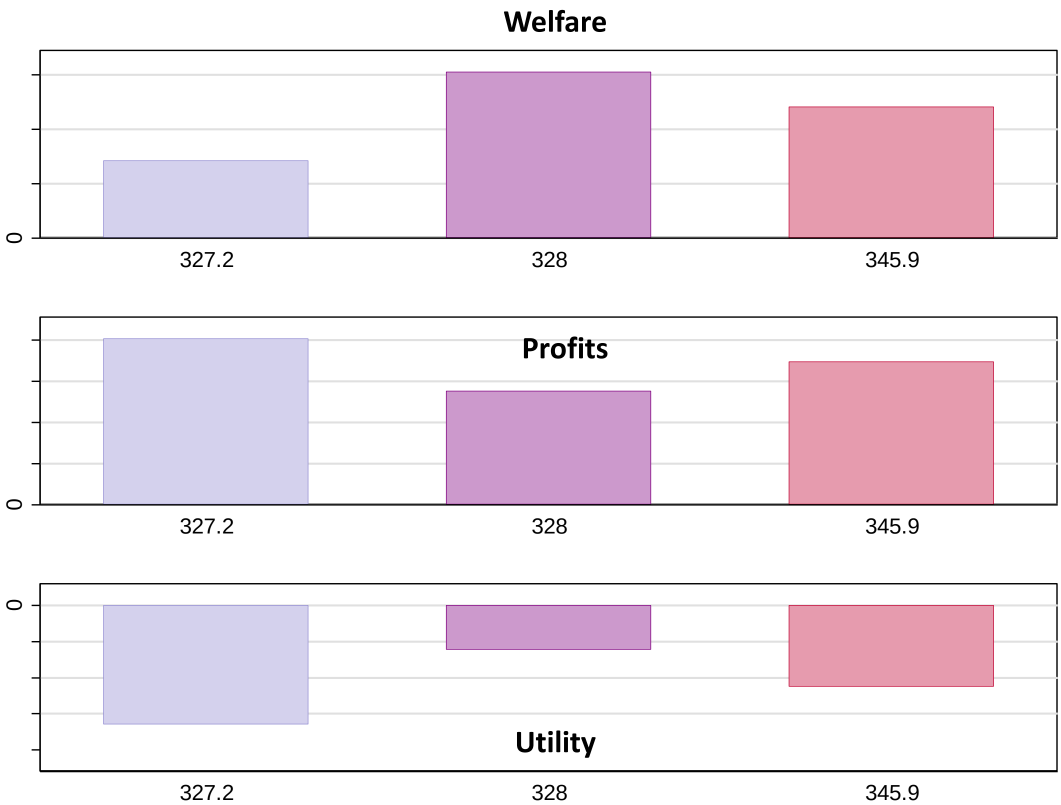

Figure 3: Welfare, Profits and Utility in the multiple equilibria

5 Robustness checks and policy analysis

We will soon try to identify whether there are other equilibria in the range of 327.23 to 345.9 expected entrants, and to what extend welfare is larger in any other equilibria in the interior set.

And we will analyse to how large should be the percentage of electric vehicle in the city to make any network of fast charging stations self-sustainable in the free market solution.

6 Concluding remarks

This paper simulates a full game of strategic interaction for modelling entry in the industry of the fast charging stations for electric vehicles. It uses the information of mobility in the city of Barcelona of both residents and commuters together with income and demographic data, and also the information of the road network and petrol stations, amenities and super/hypermarkets to simulate the equilibria of the game.

Multiple equilibria is achieved with a expected entry in the range of 327.2 to 345.9 nodes out of 891 when electric vehicle penetration reaches 5 percent. a According to the simulations, unregulated solution may lead to both slight insufficient or an excess of entrance, leading in the worst scenario to a lost in welfare of 12.5 percent.

A network of fast charging stations, however, has proved to be self-sustainable when this 5 percent penetration rate of the electric vehicle is reached. Also, that the business stealing effect seem not to play an important role, as firms tend to cluster together around the denser traffic paths.

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