# Fast Charging Stations: Simulating Entry and Location in a Game of Strategic Interaction

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Economics for Energy
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# Outline

# Some background

- **Reduction of carbon dioxide emissions**
- **Decarbonization of road transport**
  - Road transport contributes around one-fifth of the total Eu's total emissions of $CO_2$
- Transportation white paper 2011. By 2050:
  - **No more conventionally fueled cars in the cities**
  - 50% shift of intercity passenger and freight from road to rail and waterborne transport

# Main alternative to conventional cars: Electric Vehicle

**Main barriers** perceived by consumers:

- High price of vehicles (Larson et al., 2014; Helveston et al. 2015)
- Development of a network of fast charging stations. "Range anxiety" (Dumortier et al. 2015; Gnann et al. 2015)
- Battery life (Morgan Stanley 2017)

# Publicly available stations:

| | Existing Infrastructure (2011) | Proposed targets of publicly accesible infrastructure by 2020 | Plans for EV by 2020 |
|---|---|---|---|
| Austria | 489 | 12,000 | 250,000 |
| Belgium | 188 | 21,000 | - |
| Bulgaria | 1 | 7,000 | - |
| Cyprus | - | 2,000 | - |
| Czech Republic | 23 | 13,000 | - |
| Germany | 1,937 | 150,000 | 1,000,000 |
| Denmark | 280 | 5,000 | 200,000 |
| Estonia | 2 | 1,000 | - |
| Greece | 3 | 13,000 | - |
| Finland | 1 | 7,000 | - |
| France | 1,600 | 97,000 | 2,000,000 |
| Hungary | 7 | 7,000 | - |
| Ireland | 640 | 2,000 | 350,000 |
| Italy | 1,350 | 125,000 | 130000 (by 2015) |
| Lithuania | - | 4,000 | - |
| Luxembourg | 7 | 1,000 | 40,000 |
| Latvia | 1 | 2,000 | - |
| Malta | - | 1,000 | - |
| Netherlands | 1,700 | 32,000 | 200,000 |
| Poland | 27 | 46,000 | - |
| Portugal | 1,350 | 12,000 | 200,000 |
| Romania | 1 | 10,000 | - |
| **Spain** | **1,356** | **82,000** | **2,500,000** |
| Slovakia | 3 | 4,000 | - |
| Slovenia | 80 | 3,000 | 14,000 |
| Sweden | - | 14,000 | 600,000 |
| United Kingdom | 703 | 122,000 | 1,550,000 |

**Source: European Comission MEMO 24-01-2013**

# Outline

# Objectives

- **The research questions:**

- Is it necessary to establish a **system of incentives** to have a network of fast charging stations?
- In a free market scenario firms would tend to **cluster or** to **spatially differentiate** from competitors?
- Does **free market** lead to achieve maximum **social welfare**?

- **What we do:**

- Simulation of the localization of the fast charge stations by the means of a Free Entry Game of Strategic Interaction.
- Comparison of localization between:
  - individual competitors and monopoly entry.
  - free and regulated homogeneous price settings.
- Comparison of welfare in a free and in a regulated homogeneous price settings.

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# Outline

# Previous literature. Network planning for EV

**Common feature: Central planner view**

- Ip et al. (2010): two stage method. In stage 1 demand is identify by hierarchical cluster and in stage 2 charging stations are assigned to the demand clusters such as to minimize the total operational cost.

- Xi et al. (2013): maximize their use by private owners and account for the impact of EV driving patterns.

- Dong et al. (2014): locate facilities as to minimize the 'missed trips' (trips that couldn't be done without the existence of public charging) subject to a budget constraint.

- Wang and Lin (2009): minimizing the total costs of locating fast charging stations for inter-city trips.

- Wang and Wang (2010): new hybrid set-covering model where not only location costs are minimized but also population coverage is maximized.

# Previous literature. Clustering or Spatial differentiation?

- Theory: ambiguous
  - Minimum differentiation (Hotelling, 1929)
  - Maximum differentiation (D'Aspremont and Thisse, 1979)
  - For oligopolies with heterogeneous consumers: minimum differentiation (Anderson, DePalma and Thisse, 1992)

- Empirical papers: mixed results.

  Netz and Taylor (2002): *'Any equilibrium can be obtained depending on the assumptions of the model'*

  - Clustering (Borenstein and Netz, 1999; Salvanes et. al., 2005; Pinske and Slade, 1998; Vitorino, 2011)
  - Spatial differentiation (Netz and Taylor, 2002; Seim, 2004)

# Our contributions

1. **We answer whether is feasible or not the entry of independent firms to a market of fast charging stations without public transfers or subsidies**

2. **We study clustering and spacial differentiation**

# Outline

# Main features

- Set of $j$ **feasible locations**
- **Mobility of consumers** is taken into account *(Houde, 2012)*
- **Individuals** $i$ are heterogeneous regarding **commuting path** $(o_i, d_i)$ and **income** $(\mathbf{Y}_i)$**(BLP, 1995)**
- The feasible **locations** $j$ are differentiated regarding **costs** and **attractiveness** for the demand (common knowledge)
- **Unobserved idiosyncratic tastes across consumers and unobserved cost shifter across locations** are independent and identically distributed

# Main components- Supply side

**Probability of entry to location j $\rightarrow$**

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

**E($\pi_j$) different components:**

- *fixed costs*

$$\begin{cases} \text{Common component in equipment } (f) \\ \text{greed reinforcement cost } (\sum_{r=1}^{R} \mu^r z_j^r) \\ \text{localization cost } (\omega_j) \text{ and random draw} \end{cases}$$

- *expected mg costs: depend on the expected sales*
- *expected sales*

$$\begin{cases} \text{Price at } j \ (p_j) \\ \text{Probability of } i \text{ of recharging at } j \ (\Phi_{ij}) \\ \text{Energy needs } (e_i) \end{cases}$$

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# Main components- Expected sales

1- Firms compete a la *Bertrand* ($p_j$)

2- Probability of $i$ of recharging at $j$:

$$\Phi_{ij} = \frac{\exp[\phi_{ij}]}{1 + \exp[\phi_{ij}] + \sum_{k=1,k\neq j}^{J} \sigma_k \exp[\phi_{ij}]} \tag{2}$$

Indirect utility of recharging at $j$ components:

- Disutility of deviation from commuting path
- utility from amenities at $j$
- disutility of paying posted prices $p_j$
- interaction $Y_i p_j$
- idiosyncratic tastes of consumers ($\varepsilon_{ij}$)

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# Main components- Expected sales

3- Energy needs:

- kilometers/year $D(o_i, d_i)$
- energy consumption per kilometre ($C_0$)
- share of the electric vehicle ($\upsilon$ )
- share of consumption of the electric vehicle recharged on the go ($\tau$)

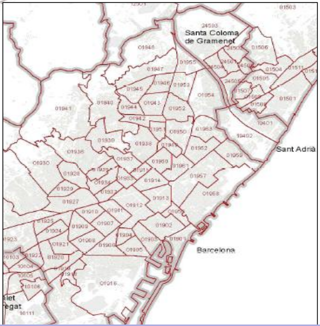
# Outline

# Case of study: Barcelona

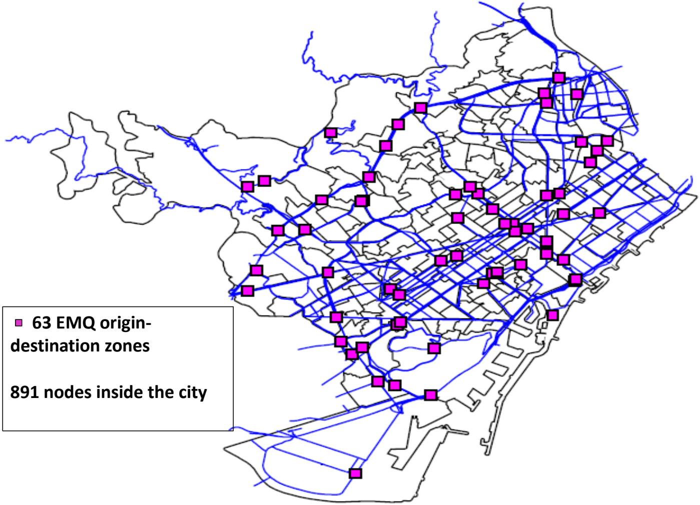
# Mobility Survey from AMT and GenCat. Year 2006

↑
308 EMQ zones

63 EMQ zones within Barcelona →



# Simplified Catalonia Roads Graph. City of Barcelona



■ **63 EMQ origin-destination zones**

**891 nodes inside the city**

# Neighborhoods of Barcelona and Censal Zones Maps

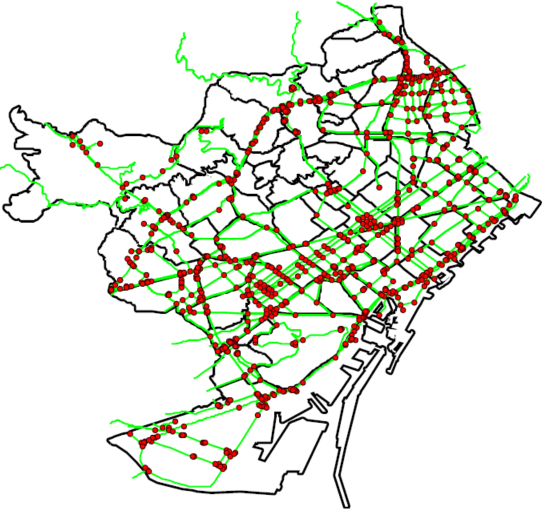
Population and geographical data

+

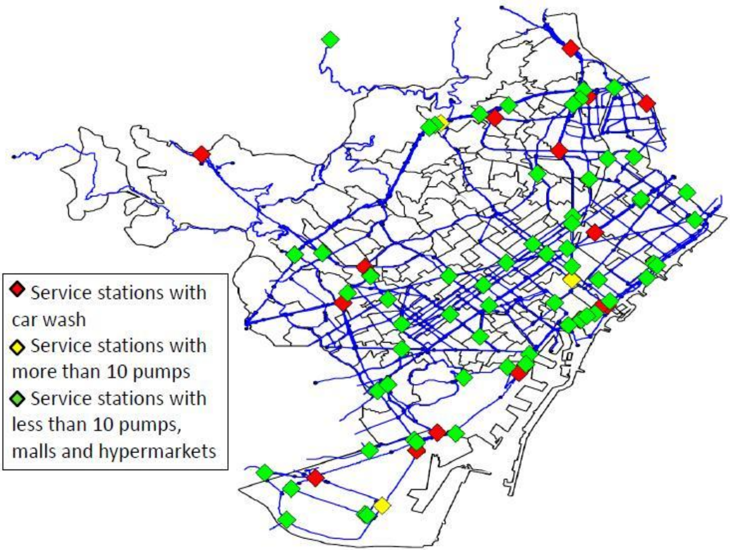
Kriging techniques

=

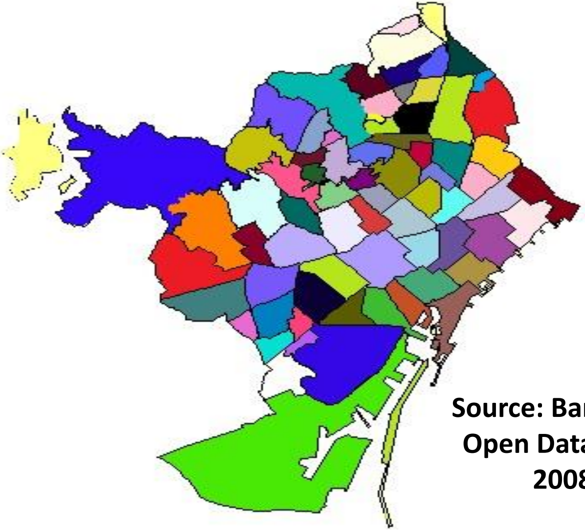
From 63 to 891 origin destination zones



# Map of fuel stations, hypermarkets and malls



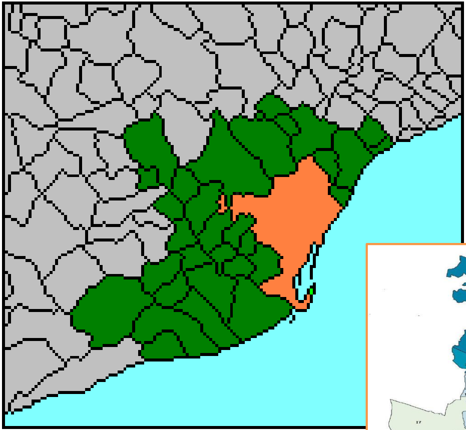
# Rent of commercial property in the different neighborhoods



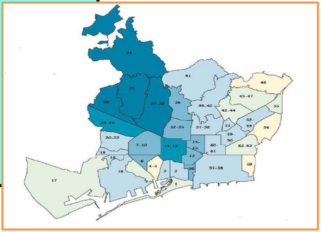
**Source: Barcelona Open Data, year 2008**

# Income Data

**Income of commuters with Diputacio de Barcelona and GenCat (Idescat) data**



**38 Income areas within Barcelona from a study of the Ajuntament de Barcelona, year 2005**



# Outline

# The simulation process

- Integrate logit demand using a sample of 100 respresentative individuals *a la* BLP.
- Probability of entry obtained by a simulation process including the simultaneous determination of:
  - *probability for individual* $i$ *of recharging at* $j$
  - *the Bertrand equilibrium price at each feasible location* $j$
  - *the probability of entry at* $j$
- The simultaneous non-linear entry-game problem was solved in Matlab by iterations

# Searching for multiple equilibria

- Obtain 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;
- Obtain 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;
- Run the entry game from both extreme solutions to look for the equilibria: Herculean equilibrium, Sanchez-Espin & Parra (2018)

# Monopoly

*System of price equations from the FOCs:*

$$p_j = c_j + \Delta^{-1} \sum_{i=1}^{I} \Phi_{ij} q_i \tag{3}$$

where $\Delta$ is a $J$ by $J$ matrix, whose $(j,k)$ element are given by:

$$\Delta_{j,k} = \frac{-\partial(\sum_{i=1}^{I} \Phi_{ik} q_i)}{\partial p_j} \tag{4}$$

and the $(j,j)$ elements are given by the facility $j$ own price elasticity:

$$\Delta_{j,j} = \frac{-\partial(\sum_{i=1}^{I} \Phi_{ij} q_i)}{\partial p_j} \tag{5}$$

# Social welfare

$$E(W) = E(CS_i) + E(\pi_j) \tag{6}$$

$$E(CS_i) = \frac{Y_i}{\alpha_i p_j} E[max_j(\phi_{ij} + \varepsilon_{ij})] \tag{7}$$

- $\frac{\alpha_i p_j}{Y_i}$ marginal utility of income;
- $max_j(\phi_{ij} + \varepsilon_{ij})$ alternative that provides the greatest utility to consumer i.

The results presented are from simulating 100 times $\varepsilon_{ij}$ following a type-one extreme value distribution.

# Outline

# The Equilibria Description

Table 1: Equilibria at 1%, 3% and 5% of penetration of EV

| *Variable/ Share EV* | *1%* | *3%* | *5%* |
|---|---|---|---|
| *Number of entrants* | 2 | 51 | 83 |
| *Share 'on the go' (%)* | 0.482 | **8.06** | 9.47 |
| *Mean Price (euros)* | 25.09 | 18.87 | 18.55 |

**Result: A network of fast charging stations overcome range anxiety from a 3% penetration rate**

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# The Equilibria Description

Table 2: Characterization of locations at 1%, 3% and 5% of penetration of EV

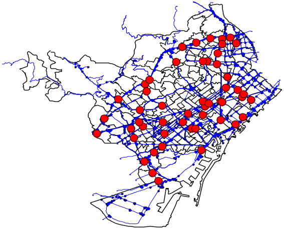
| *Variable/ Share EV* | *1%* | *3%* | *5%* | *Total feasible locations* |
|---|---|---|---|---|
| *Number of locations* | 2 | 51 | 83 | 891 |
| *Amenities* | 100% | 100% | 75% | 8.4% (75) |
| *Grid reinforcement costs* | | | | |
| *Type 1 (0 cost)* | 0% | 23.5% | 19% | 2.24% (20) |
| *Type 2 (half cost)* | 0% | 4% | 4% | 0.45% (4) |
| *Type 3 (full cost)* | 100% | 72.5% | 77% | 97.3% (867) |
| *Localization costs (average euros)* | 2250 | 1786 | 1791 | 1811 |

**Result: Demand drivers are more important in determining location**

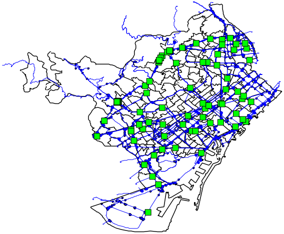
# Localization within Equilibria

1% Share Electric Vehicle

3% Share Electric Vehicle



5% Share Electric Vehicle



# Counterfactual Clustering vs. Spatial Differentiation

Table 3: Distance between competitors measured in deviations of the consumers

| *Share EV- Entrants* | *5%- 83* | | |
|---|---|---|---|
| | *Free* | *Regulated* | *Monopoly* |
| *Average deviation (m)* | 144.84 | 127.23 | 9.67 |
| *ttest* | | 1.7724* | 17.9419*** |

Note: statistical significance at 1% (***), 5% (**) and 10% (*).

**Result: Free ≻ Regulated ≻ Monopoly**

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Table 4: Distance among competitors measured in Euclidean and shortest path distances

| *Distance* | *In space -Euclidean-* | | | *In the network -shortest path-* | | |
|---|---|---|---|---|---|---|
| *Miles* | *half* | *one* | *two* | *half* | *one* | *two* |
| *Regulated price* | 479.3 | 938.8 | 1787.9 | 480.9 | 910.2 | 1822.7 |
| *Independent firms* | 457.8 | 902.9 | 1748.5 | 461.0 | 872.9 | 1776.5 |
| *ttest* | -0.63 | -0.77 | -0.85 | -0.51 | -0.69 | -0.75 |
| *Monopoly* | 361.8 | 720.6 | 1052.5 | 373.4 | 702.4 | 1088.2 |
| *Independent firms* | 457.8 | 902.9 | 1748.5 | 461.0 | 872.9 | 1776.5 |
| *ttest* | 3.3*** | 4.3*** | 12.0*** | 2.7*** | 3.7*** | 10.7*** |

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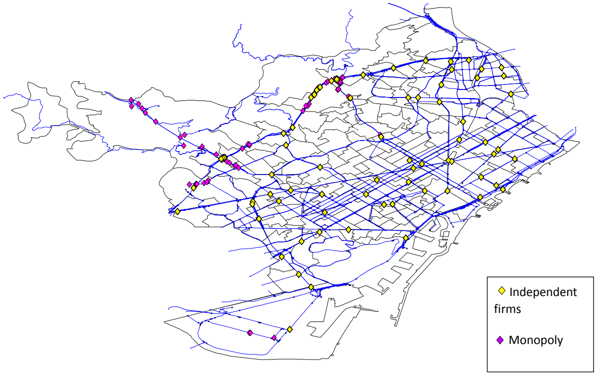
# Counterfactual Clustering vs. Spatial Differentiation

Figure 1: Locations equilibria at 5% penetration rate: monopoly vs. independent competitors



# Counterfactual Welfare

Table 5: Welfare decomposition and evolution. Free vs Regulated Pricing

| *Share EV* | *3%* | | *5%* | |
|---|---|---|---|---|
| *Setting* | *Free* | *Regulated* | *Free* | *Regulated* |
| *Price (euros)* | 18.87 | 16 | 18.55 | 26 |
| *Number of entrants* | 51 | 51 | 83 | 83 |
| *Utility (million euros)* | 2,023.3 | 3,573.6 | 3,519.0 | 2,552.8 |
| *St. dev. (million euros)* | 69.3 | 80.2 | 124.9 | 127.7 |
| *Expected Profits (euros)* | 784,253 | 587,677 | 1,679,874 | 2,238,592 |
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Table 6: Welfare decomposition. Free setting vs regulated locations. 3% scenario

| *Setting* | *Free* | *Gasoline st.* | *Random* | *One zone* |
|---|---|---|---|---|
| *Number of entrants* | 51 | 74 | 51 | 51 |
| *Utility (million euros)* | 2,023.3 | 1,969.5 | 405.1 | 390.0 |
| *St.dev.(million euros)* | 69.4 | 76.2 | 62.8 | 37.1 |
| *Expected Profits (euros)* | 784,253 | 553,340.37 | 56,495 | -98,981 |
| *Total Welfare (million euros)* | 2,024.1 | 1,970.0 | 405.1 | 389.9 |

**Result:** → **Free** ≻ **Gasoline st.** ≻ **Random** ≻ **One zone**

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| *Setting* | *Free* | *Gasoline st.* | *Random* | *One zone* |
|---|---|---|---|---|
| *Number of entrants* | 51 | 74 | 51 | 51 |
| *Utility (million euros)* | 2,023.3 | 1,969.5 | 405.1 | 390.0 |
| *St.dev.(million euros)* | 69.4 | 76.2 | 62.8 | 37.1 |
| *Expected Profits (euros)* | 784,253 | 553,340.37 | 56,495 | -98,981 |
| *Total Welfare (million euros)* | 2,024.1 | 1,970.0 | 405.1 | 389.9 |

**Result:** $\rightarrow$ **Free** $\succ$ **Gasoline st.** $\succ$ **Random** $\succ$ **One zone**

Table 7: Welfare decomposition. Independent competitors vs Monopoly

| *Setting* | *Independent firms* | *Monopoly* |
|---|---|---|
| *Number of entrants* | 83 | 361 |
| *Utility (euros)* | 3,519,014,534 | 1,339,784,013 |
| *Standard deviation* | 69,347,928 | 180,872,477 |
| *Expected Profits (euros)* | 784,253 | 86,481,175 |
| *Total Welfare (euros)* | 3,520,694,408 | 1,426,265,188 |

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# Robustness checks

- **Demand parameters:**
  - Travel cost
  - Price elasticity at $j$
  - Price elasticity of recharging on the go respect to at home
  - Consumers price sensitivity
  - Consumers amenities preference
- **Sample:**
  - Six additional random samples
  - One young and reach sample
- **Comparison of results with 5 European cities**

# Outline

# Conclusions (I)

- A network of fast charging stations has proved to offer a solution for "range anxiety" when a 3% penetration rate of the electric vehicle is reached.
  - From 3% there is no need of fiscal transfers
  - The threshold is around 15 times higher than the current penetration rate in Barcelona

- Demand drivers seem to have a stronger influence than entry costs in determining the localization of the fast charging stations.

- When competing in terms of location and price firms seem to differentiate from competitors more in spatial terms than when they are in the same setting with a uniform price or in the monopoly case.
  - "Market power effect" and "market expansion effect" seem stronger than "business stealing effect"

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# Further Research

Asses if different combinations of transfers and price regulations would provide better outcomes in terms of social welfare