Entry and Coordination in the U.S. Electric Vehicle Charging Industry by Prof. Jing Li, Dec/2/2022

Annotation written by Paul Twijukye

Part I – Related literature

Li, Shanjun & Tong, Lang & Xing, Jianwei & Zhou, Yiyi. (2017). The Market for Electric Vehicles: Indirect Network Effects and Policy Design. Journal of the Association of Environmental and Resource Economists. 4. 89-133. 10.1086/689702.
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Li (2019), Compatibility and Investment in the U.S. Electric Vehicle Market
https://www.mit.edu/~lijing/documents/papers/li_evcompatibility.pdf

Springel, Katalin. "Network Externality and Subsidy Structure in Two-Sided Markets: Evidence from Electric Vehicle Incentives." American Economic Journal: Economic Policy 13, no. 4 (November 1, 2021): 393–432.
https://doi.org/10.1257/pol.20190131

Dorsey, Jackson, Ashley Langer, and Shaun McRae. "Fueling Alternatives: Gas Station Choice and the Implications for Electric Charging," March 2022.
https://doi.org/10.3386/w29831

Sinyashin (2021). Optimal Policies for Differentiated Green Products: Characteristics and Usage of Electric Vehicles.
https://sites.google.com/berkeley.edu/alexey-sinyashin

Houde, Jean-François. "Spatial Differentiation and Vertical Mergers in Retail Markets for Gasoline." American Economic Review 102, no. 5 (August 1, 2012): 2147–82.
https://doi.org/10.1257/aer.102.5.2147

Gillingham, Kenneth. "Designing Fuel-Economy Standards in Light of Electric Vehicles," July 2021.
https://doi.org/10.3386/w29067

Holland, Stephen P., Matthew J. Kotchen, Erin T. Mansur, and Andrew J. Yates. "Why Marginal CO_2 Emissions Are Not Decreasing for US Electricity: Estimates and Implications for Climate Policy." Proceedings of the National Academy of Sciences 119, no. 8 (February 14, 2022).
https://doi.org/10.1073/pnas.2116632119

Part II - Recent News

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Laurence, T. (2022, June 20). How GM, Ford, and Tesla are tackling the national EV charging Challenge.
https://www.cnbc.com/2022/06/20/how-gm-ford-tesla-are-tackling-the-national-ev-charging-challenge.html

Charette. R. (2022, Dec 4). The EV transition explained. Charger infrastructure: How many, where, and who pays?
https://spectrum.ieee.org/the-ev-transition-explained-2658463735

Noblet, S. (2022, Nov 18). Improving EV charging infrastructure for all: Takeaways from GreenBiz Group's VERGE 22.
https://www.forbes.com/sites/stacynoblet/2022/11/18/improving-ev-charging-infrastructure-for-all-takeaways-from-greenbiz-groups-verge-22/?sh=7533d2db7367

Part III – Direct Questions

Prof. Jinhua Zhao, Director – MIT Mobility Initiative, asked the following questions:

Q: In the preliminary empirical results, it was found that adding a station 75-150 miles away increases incumbent utilization during peak hours by approximately 0.49 percentage points. How does this impact on incumbent utilization vary across different dimensions (geographies, networks, etc.)

A: The impact of 0.49 percentage points is an average estimate, and it's statistically significant. There's high variation in the impacts that we estimate; however, it's difficult to capture geographic variation because the more we zoom in on a specific area of the country, the more we lose data, and statistical precision. But, yes, there is significant heterogeneity across regions and networks in the impacts that we're estimating.

Q: Are there location or geographic pattern constraints tied to the government subsidy plan?

A: My understanding is that the IIJA plans to use a location-targeted subsidy plan rather than a uniform subsidy plan, and in our analysis, we are asking whether economic theory or evidence can justify that specific way of designing subsidies.

Q: On the purely private sector side, are private companies building out their charging networks in an efficiently coordinated way?

A: From our analysis, we see that when an entrant is the special last one that connects a given route, they're more likely to share the dominant network with incumbents compared to if they're just an entrant that's further densifying a network and that makes sense. So, I think there's certainly a bit of coordination happening. In fact, by looking at the charging network maps, one can tell that there is some coordination going on. In our analysis, we're trying to figure out a nice way of quantifying coordination on a numerical scale so that you could take a given network and ask how much coordination is happening.

Q: Ideally, we would like to have a common charging standard across most of the U.S.; however, trying to impose standardization requirements/mandates could get rid of incentives for private companies to set up their own charging networks. On the other hand, the lack of standardization requirements/mandates could lead to a situation where there are so many different charging standards, hence, resulting in incompatibility issues. What are your thoughts?

A: If you leave the market to decide on standards and compatibility on its own, no firm has the incentive to provide two-sided compatibility. From a policy perspective, we don't generally have a precedent of mandating standardization and compatibility. Across many industries, standardization tends to be something we've left up to industries to sort out on their own through industry, standard-setting organizations. With regards to how the IIJA plans to spend the 5 billion USD, the U.S. government has specified that this funding is only accessible to charging stations that are more open to EV cars of different brands – this, therefore, excludes Tesla.

<u>Mr. John Moavenzadeh, Executive Director – MIT Mobility Initiative, moderated the following queries from some questions raised by the audience:</u>

Q: Induced demand observed on a given route, arising from an entrant completing the route at a given mile range, may be from EV drivers shifting from the utilization of an alternate route/corridor. In this scenario, although the completion/electrification of a route at a given mile range is leading to positive spillover effects for incumbent charging stations on the given route, these positive effects are accompanied by negative spillover effects for incumbents on alternate routes. Are you taking such scenarios into account?

A: At the moment, our empirical analysis doesn't take such scenarios into account, though I agree that this is something that would be important to look at in the short run/early stages of the EV industry.

Q: It seems like the build-out of EV charging infrastructure parallels the build-out of cell towers. Are there records to depict cell tower build-out from 25 years ago? In your research, have you looked at the rollout for other networks and how these rollouts compare to the EV charging network build-out?

A: I've looked at cell towers and the rollout of gas station retail back in the day. I found descriptive evidence that these networks built out in a spatial pattern that followed population densification i.e., the networks built out from wherever the population was dense. However, I couldn't find detailed data to understand who was doing that investment and how many firms there were.

Q: How do topography and climate impact this analysis if at all? We know that EV range correlates with topography and climate, so one would expect charging locations to correlate with these factors as well. In other words, will mountainous cold regions need more charging infrastructure than flat hot ones?

A: I agree with you that that is important richness to capture; however, we haven't gotten far enough in the analysis to add that level of detail. For example, when I link a charging station to a road, I am not keeping track of which side of the road it lies on. This is yet more richness that could be added to the analysis because for example, if you are going up a mountain, you would want more stations on the side of the road that leads up the mountain.

Q: As far as the route level analysis goes, how is a charging station determined to be on a route? Is it based on a certain distance from the highway? If the latter, how sensitive are the estimates to variation in the preset distance from the highway?

A: The preliminary analysis I am doing is using half a mile away. According to the U.S. government, a corridor is regarded as an EV corridor if it's 0.1 miles away from the highway. Previously, the government was using a distance of 0.5 miles. Ultimately, our plan is to use both 0.1 and 0.5, so I'll be reporting back on the robustness of the results in the future.

Q: Do you think we will end up in a situation where private companies like Tesla dominate the EV charging market, or do you see the government successfully subsidizing the rollout of many EV charging stations?

A: I don't get the sense that the EV charging market is on the cusp of turning into a monopoly; at least at the moment since in the EV market, we have cars that only work with a subset of charging stations. There is definitely going to be variation, over time, in how EV charging stations are maintained.

Q: Governments tend to offer entrants capital money for entry upfront. However, due to high demand charges and operational costs, most people aren't able to maintain these charging stations despite successful entry into the EV charging market. To solve this problem in the short term, is the solution to come up with a regulatory rate structure reform as opposed to just providing capital money upfront, which governments like to do?

A: Energy economists much more senior than I have long been writing op-eds about the inefficiencies of demand charges, not just in the EV industry, and they find it to be a very inefficient way to recover capital costs for the utility. Critical peak pricing is something that energy economists say is a nice complement or alternative to demand charges, so maybe, that's something to consider. Additionally, charging stations could coordinate demand so that they don't get as many peaks – this would help lower their demand charges.

Part IV - Summary of Memos

1. Michael mentioned that Prof. Li's talk inspired him to think about how the economics of networked (essential) services evolve as adoption increases. Michael felt that examining the similarities of the rollout of EV charging infrastructure to the rollout of gas stations, telecom networks, power grids, and other similar situations would be interesting. Michael also pointed out that understanding the role/impact of the government in the rollout of other networked systems may also be of interest.

2. Yen-Chu was left wondering whether a network-level analysis was possible as opposed to a station/route-level analysis. If possible, he felt that a network-level analysis would be better suited to capture certain interaction effects/impacts between alternate routes.

3. McKenzie had a question about how electric charging companies would choose secondary or tertiary routes to connect after interstate highways were sufficiently covered. She also wondered whether spillover effects would lead companies to coordinate station siting to complete a network connection more quickly, or whether the identified network effects incentivized separate network-building efforts.

4. Ao Qu had a question about how information transparency about charging stations affects people's willingness to own and use electric vehicles. He also wondered whether, from a mathematical modeling perspective, it was possible to develop a technique for evaluating the marginal effect of all candidate locations to allow for more efficient station siting.

5. Acharya asked about the characteristics of the locations that were "holes" in the routes. She also wondered whether there were any other social spillovers of subsidizing charging infrastructure in underprovided locations. Acharya also brought up an interesting point about how in the base case where there are holes in routes, we are implicitly assuming that the drivers do not drive at all -- yet there could be other possibilities of alternate routes, public transport utilization, gasoline car usage, etc. If we were to factor these in, Acharya wonders how it would impact the analysis and the definition of positive/negative spillovers.

6. Tushar, and Spencer felt that the usefulness of charging infrastructure efficiency remains a question that can only be answered once a fully deployed electric vehicle ecosystem takes off. Furthermore, Tushar felt that the idea that there could be a merger of different charging infrastructure systems could further disrupt the ‘support structure’ for mass-scale EVs, and therefore the questions, and the respective econometric modeling required to answer them, will need to evolve as the shape of the future of charging systems becomes more apparent.

Part V - Reflection

Prof. Jing Li delivered an interesting talk on entry and coordination in the U.S. electric vehicle charging industry. In light of the IIJA devoting $5 billion toward setting up EV charging infrastructure every 50 miles on interstate highways, Prof. Jing Li has been trying to understand how the government should best use the $5 billion i.e. if charging networks are efficiently coordinating charging station entry, then the government should offer uniform subsidies; however, if charging networks are not efficiently coordinating charging station entry, then the government should offer more targeted subsidies to help fill the holes in the existing charging networks. To get a better understanding of the current EV charging market, Prof. Jing Li set out to determine whether charging stations had spillover effects on each other. Preliminary analyses done at the charging station and route levels revealed positive spillover effects for specific mile ranges. These results, albeit preliminary, point towards charging stations having spillover effects on each other both at the station and route levels. Given these spillover effects, Prof. Jing Li is currently trying to understand whether charging networks are efficiently coordinating charging station entry.

Several interesting points came up during the talk:

- The route level analysis looked at how the utilization rates of incumbents (already existing charging stations) changed when a new charging station/entrant electrified a route at a given mile range. Although one may see positive spillover effects, say at the 50-mile range, on the utilization rates for incumbents along the route being considered, it’s highly likely that there may be negative spillover effects on charging stations along alternative routes/corridors i.e., the induced demand observed on a given route, arising from an entrant completing the route at a given mile range, may be from EV drivers shifting from the utilization of an alternate route. In this scenario, although the completion/electrification of a route at a given mile range is leading to positive spillover effects for incumbent charging stations on the given route, these positive effects are accompanied by negative spillover effects for incumbents on alternate routes.

- How do government subsidies actually work? Are these subsidies only meant to help cover the fixed costs of setting up an EV charging station? I don’t see such subsidies being extremely helpful for entrants. As Prof. Jinhua pointed out during the talk, charging stations, like gas stations, make most of their revenue from auxiliary functions around the station. Simply helping an entrant cover their fixed cost of entry might not be enough since it’s highly likely that an entrant without enough revenue to cover their fixed cost of entry also doesn’t have enough income to cover the daily operational costs that go along with maintaining an EV charging station. Therefore, given the dependence of most charging stations on auxiliary functions for income generation, government subsidies should go beyond simply helping an entrant cover their fixed cost of entry to guarantee the long-term survival of the charging station.

- The suggested government subsidies are to be offered to entrants looking to set up charging stations that allow for diverse EV users. In the short term, I can see this having a positive impact in the sense of increasing the number of EV users by making a broader range of EV cars operable over several major interstate highways. In the long term, what impact does such government intervention have?

Entry and Coordination in the Electric Vehicle Charging Industry

Jing Li [1] Katalin Springel [2]

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MIT Mobility Forum
December 1st, 2022

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- Spillovers in entry decisions
  - Usually negative from business stealing
  - Positive in network settings (ride-sharing, telecommunications, etc.)

- Potential for inefficiently low entry, which could warrant government policies

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  - Usually negative from business stealing
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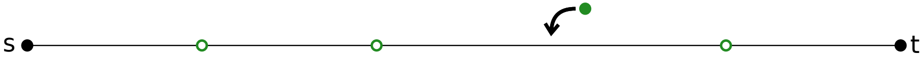
- Potential for inefficiently low entry, which could warrant government policies
- This project: Elecric vehicle charging station entry decisions
  - Does the market coordinate entry efficiently?
  - Can targeted subsidies improve market efficiency?

An entrant may have positive spillovers on others along the same route



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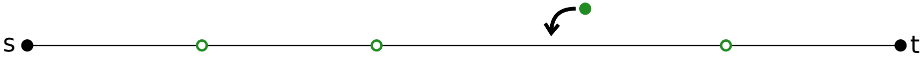

- The last entrant to "connect the dots" can increase value of far-away incumbents

An entrant may have positive spillovers on others along the same route

- The last entrant to "connect the dots" can increase value of far-away incumbents
- The last entrant's private value of entry also depends on the set of incumbents
- Positive spillovers + independent entry decisions $\Rightarrow$ inefficiently low entry

2021 IIJA: $5 billion for EV charging stations every 50 miles

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"Right now it's patchy—some places where you wouldn't have a problem, other places where you would. We need to make [EV charging] universal."

"Do we need support for gas stations? We don't [...] Delete it."

Research questions

1. Are there positive spillovers across electric vehicle charging sites?
2. Is entry inefficiently low in some places?
3. What are the efficiency implications of the IIJA guidelines compared to alternative policies, such as a uniform subsidy?

Project roadmap

- **Reduced-form estimates**
  - Spillover test 1: impact of entry on incumbents at different distances
  - Spillover test 2: impact of a route becoming connected on incumbents along the route
  -

- **Model**
  - Consumer demand for vehicles and charging services
  - Entry decisions by charging station site hosts
  - Charging network pricing for both sides of the market

- **Counterfactuals:** simulate charging network build-out and utilization for:
  1. A uniform subsidy and the US government NEVI program guidance (February 2022, completing highway corridors at most 50 miles apart)
  2. Charging network merger

Plan for today

- **Reduced-form estimates**
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- **Model sketch**
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Literature

EV markets

- Charging networks: Springel (2021), Li (2019), Li, Tong, Xing, & Zhou (2017),
- Energy and emissions: Gillingham et al (2022), Holland et al (2022), Holland et al (2016)
- Driver behavior: Sinyashin (2022), Dorsey et al (2022), Houde (2012)
- This paper: Whether charging station entry subsidies should be targeted, novel data

Firm entry

- Endogenous product/location: Holmes (2011), Jia (2008), Seim (2006), Mazzeo (2002)
- Competitive effects: Arcidiacono et al (2020), Goolsbee & Syverson (2008), Whinston & Collins (1992)

Assortment optimization with multiple categories basket shoppers

- Cachon and Kök (2007)

Bargaining in platforms and vertical markets

- Ho and Lee (2019), Collard-Wexler et al (2018), Crawford et al (2018), Crawford & Yorukoglu (2012)

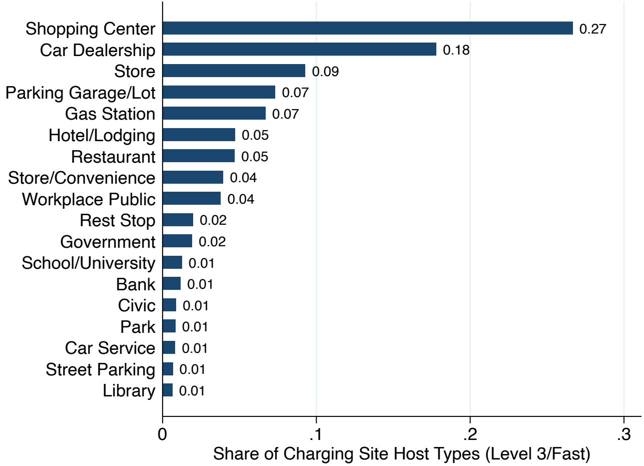
Roadmap of talk

1. **Industry background & Data**
2. Reduced-form estimates
    a. Spillover test 1: station-level
    b. Spillover test 2: route-level
3. Model

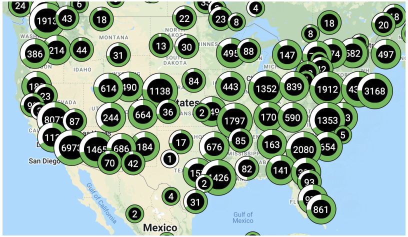
Electric vehicle charging primer

- Charging stations
  - Collections of charging posts
  - Offered by site hosts
  - Independent or affiliated with a network
- Standards: still 3 different Level 3 (fast) standards in the U.S.
- Retail prices
  - Set by site hosts or network
  - Linear, nonlinear, TOU
  - In energy or time

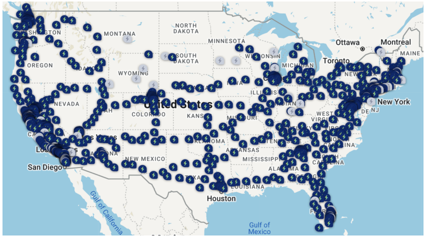
Charging site hosts vary in their primary purpose or business



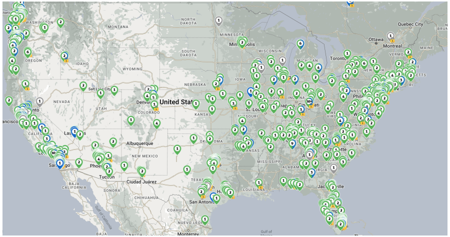
Charging network companies differ in build-out strategies



(a) ChargePoint



(b) Electrify America



(c) Blink

(d) Tesla

Data

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  - Safegraph: anonymized mobile data from 45 million devices
  - By home census block group, specific establishments visited and frequency of visits

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- **Charging location and attributes**
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  - Entry date, GPS coordinates, connector count/types, price, network affiliation, amenities
- **Charging location utilization**
  - Status by station at 30-min intervals; 2015, 2016 (all US) and Nov 2021 - present (CA only)
  - 1.6 million check-ins and reviews from a crowd-sourced website/app from 2011 - present

Roadmap of talk

1. Data & Industry background
2. **Reduced-form estimates**
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Empirical test for spillovers

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- **Estimating equation:**

$$y_{jt} = \beta_0 + \sum_d \beta_d \Delta \text{Competitors}_{jdt} + \gamma_j + \gamma_t + u_{jt},$$

  where d denotes distance bands from incumbent j.

- Caveat: (currently) no instrument for entry (suggestions welcome!)
  - Key identification assumption: Unobserved demand shocks are local $\Rightarrow$ no common unobserved demand shocks far away.
  - One possibility is EV subsidies as a demand shifter

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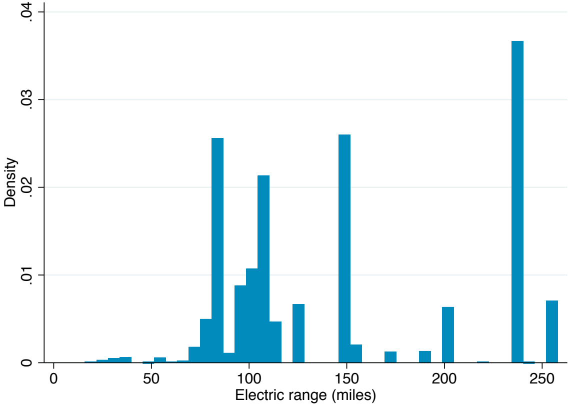
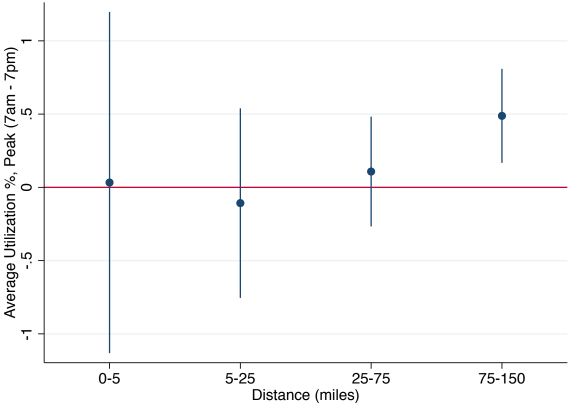
- Expect differences depending on whether charging standards are shared. Two cases:
  1. Entrants and incumbents share charging standards
  2. Entrant on a different charging standard

At what distances should we expect effects?



- Car range is upper bound on spacing of charging trips.
- Significant share of cars charging at these stations have range of 75-150 miles.
- For now: focus on distances of 75-150 miles vs. shorter distances.
- Work in progress: explore impact of changes in range of EV fleet over time.

Impact of entrants on incumbents with shared standard



- Preliminary estimate (please do not cite): Adding a station 75-150 miles away increases incumbent utilization during peak hours by .49 percentage points (or 3.1%).

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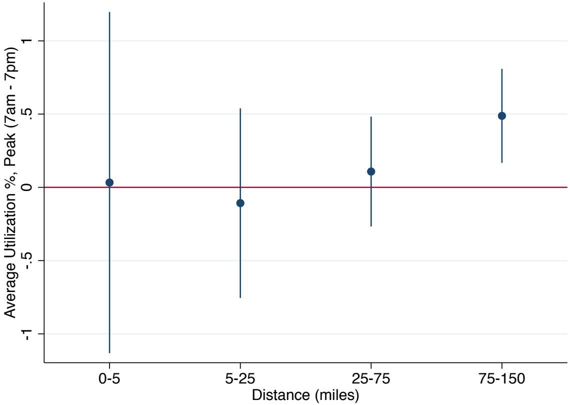
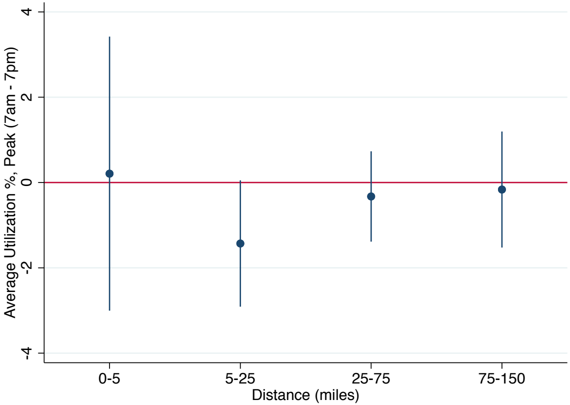


- Preliminary estimate (please do not cite): Adding a station 75-150 miles away increases incumbent utilization during peak hours by .49 percentage points (or 3.1%).
- No evidence of business stealing for short distances (but noisy estimates)

Impact of entrants on incumbents with *different* standard

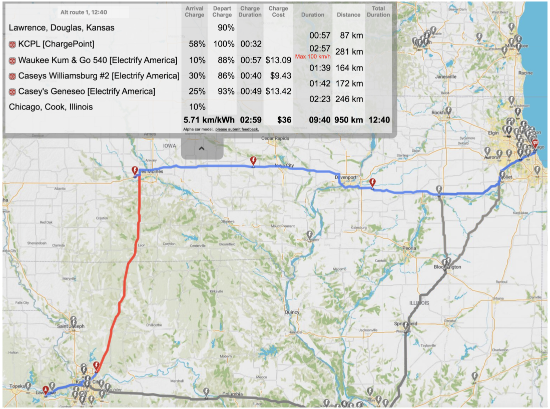


- Entry is not associated with significant (positive or negative) changes in utilization for incumbents with different standards.
- Exception: positive increases in demand 0-1 miles away. Interpretation: common demand shock.

Route-level analysis

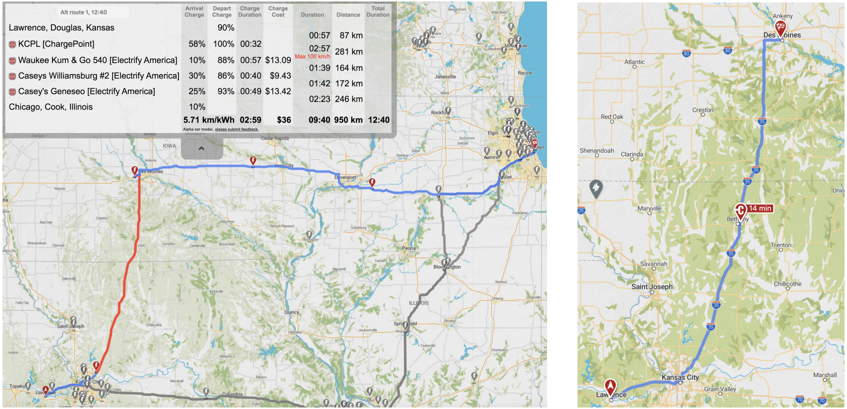
- So far: effect of entry at different distances from the incumbent, relatively coarse
- Road network allows for more structured tests
- Study impact of entry on incumbents along the same route
  - Compare impacts of entrants that ‘complete’ routes vs. earlier entrants that do not
  - Expect larger effects on previously disconnected routes
  - Plan to use state EV subsidies as a demand shifter for charging demand (not implemented in today’s results)

Illustration of entry on a specific route



(a) Lawrence, KS to Chicago, IL, 2019

Illustration of entry on a specific route

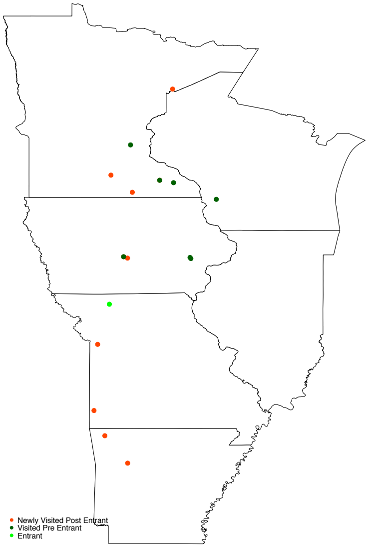


(a) Lawrence, KS to Chicago, IL, 2019

(b) 2021

Figure: EV routing in the Midwest; Source: `abetterrouteplanner.com`

User-specific data suggest spillovers from the entrant

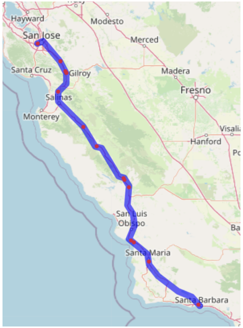


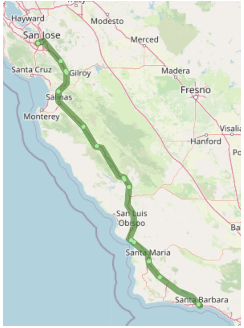
Comments about the entrant:

- “It works! Now I can get from Des Moines to Kansas City w/o major range anxiety or having to do mental math while driving.”
- “Very happy to see this charging void getting filled for non-Teslas!”
- “About 8 degrees outside. Arrived with 40% SOC. Working well. Without this Bethany station I wouldn’t make it from Des Moines to KC!”

Data construction steps with example of San Jose to Santa Barbara, CA

- Set of origins and destinations: FHWA Adjusted Urban Areas (493)
- Intersect charging stations with routes between each origin-destination pair
- Calculate distance between adjacent charging stations; a route is connected for a certain range if maximum distance is less than that range





- The new station that “electrifies” this route at the 50-mile range for the SAE J1772 Combo standard is in Los Alamos (Electrify America, entered May 2022).

Route-level analysis

- **Estimating equation:**

$$y_{rt} = \beta_0 + \beta_c \text{Connected}_{rt} + \gamma_r + \gamma_t + u_{rt},$$

  where r denotes a route, and y_{rt} is average utilization of incumbents on route r.
- β_c interpretation: impact of a route becoming connected at a certain range on incumbent utilization rates
- Identification assumption: unobserved (common) demand shocks are uncorrelated with whether a new entrant connects a route

$\Rightarrow$ Preliminary estimate, please do not cite: An entrant that “electrifies” a route at 50-mile intervals increases utilization of incumbent stations by .63 percentage points (or 25.9%) on average (in California, 2021 - present).

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- **Next question**: Do charging networks help coordinate charging locations entry?

How do charging networks compare in entry patterns?

- For each charging standard, route, and time period, compute location share by network (e.g. ChargePoint, Electrify America)
- Each route, at the time of becoming connected, has a dominant network and a set of newly arriving stations that contribute to it becoming connected.
- On a small sample of routes, YTD 2022, for the Combo standard
    - 69% of entrants are on the dominant network (EVConnect, Electrify America) when the network becomes connected, compared to
    - 62% of all entrants being on the dominant network (ChargePoint)
- Working on formulating this empirical test to something between 0 and 1 so that we have a sense of magnitude or what to make of this (e.g. how close to vertically integrated or centrally planned is this network)

Roadmap of talk

1. Industry background & Data
2. Reduced-form estimates
   a. Spillover test 1: station-level
   b. Spillover test 2: route-level
3. **Model sketch**

Model sketch

- **Goal:** Compare welfare of the ‘every-50-mile’ policy to a uniform charging station subsidy
- **Ingredients:**
  1. How drivers demand charging services given the charging network
  2. Which charging stations would be induced to enter with different subsidy eligibility rules
  3. Charging networks set entry and network fees to maximize profits

Model ingredient 1: Consumers

- Live in a market and have mobility needs
- Given charging network and their vehicle from prior choice, where to recharge when away from home.
- Disutility from time and monetary cost of charging
  - Cost of time or location distortion for charging compared to "natural" dwell time/location
  - "Opportunistic charging" (at work, shopping, waiting at a kid's weekend activity) vs. twiddling thumb at a highway rest stop
- Identification:
  - Price elasticity: Energy cost shifters from utility rates and structures
  - Elasticity w.r.t. location and inconvenience: Prior charging station subsidies, Alternative Fuel Corridor designation program

People look for charging near where they already go

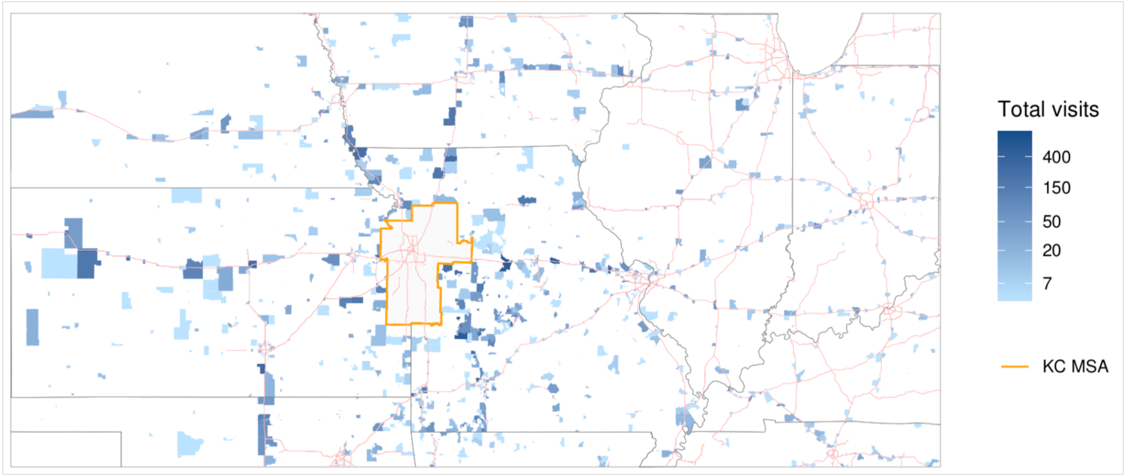
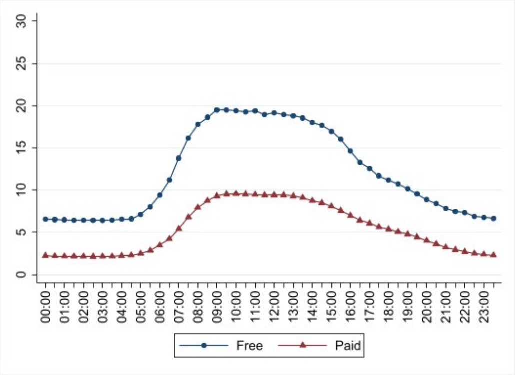
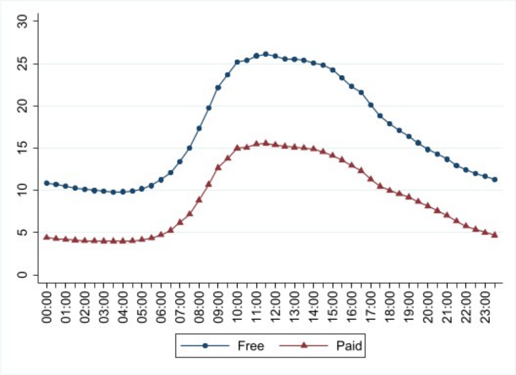


Figure: Visits to Gas Stations by People Who Live in KC, MO, Aug 2020; SafeGraph

Free stations have higher utilization than paid stations.



(a) Network X (Nationwide), Sep 2015



(b) Network X (CA Only), Nov 2021 - Feb 2022

Figure: Average Over Station-Day Observations

Model ingredient 2: Site hosts

- Endowed with a location and on-site amenity/business
- Set of possible charging station site hosts:
  - Any hotel, retail establishment, parking garage, municipal parking lot
  - Subsidy policy changes which sites are eligible
- Each period, given the charging network
  - If never entered, pay entry cost to enter
  - If previously entered, pay network fee/maintenance cost to remain active
  - If active, choose prices
- Multiple equilibria, depending on expectations (Katz and Shapiro (1985))
  - Use crowd-sourced check-in data to 'cut up' the network into independent charging markets
  - Identification from government coordination activity (Alternative Fuel Corridor designation program) and prior charging station subsidies

Model ingredient 3: Charging networks

- Intermediate between drivers and charging station site hosts.
  - Drivers pay membership fees (to the network) and marginal usage fees (split between site host and network).
  - Charging station site hosts pay a per-period network fee.
- Choose how much to subsidize either side of the market
- In counterfactual:
  - Hold fixed the organizational form of the network (e.g. vertical integration with sites)
  - Subsidy eligibility changes the entry profitability of different sites

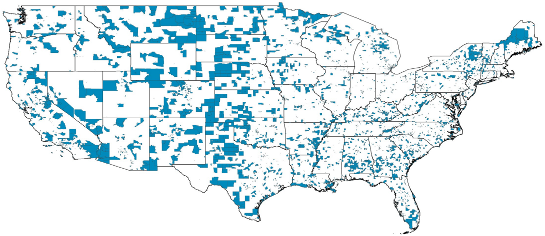
Summary and next steps

- U.S. charging station subsidy policy can be rationalized by positive entry spillovers across charging locations.

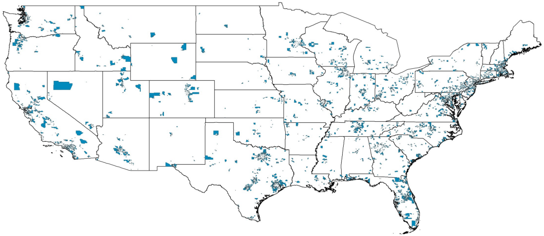
- **Next steps:**
  - Specify and estimate a structural model of the charging industry
  - Evaluate impact of a targeted every-50-mile subsidy policy compared to a uniform subsidy

THANK YOU!

Census tracts at 10th and 90th percentile by population count



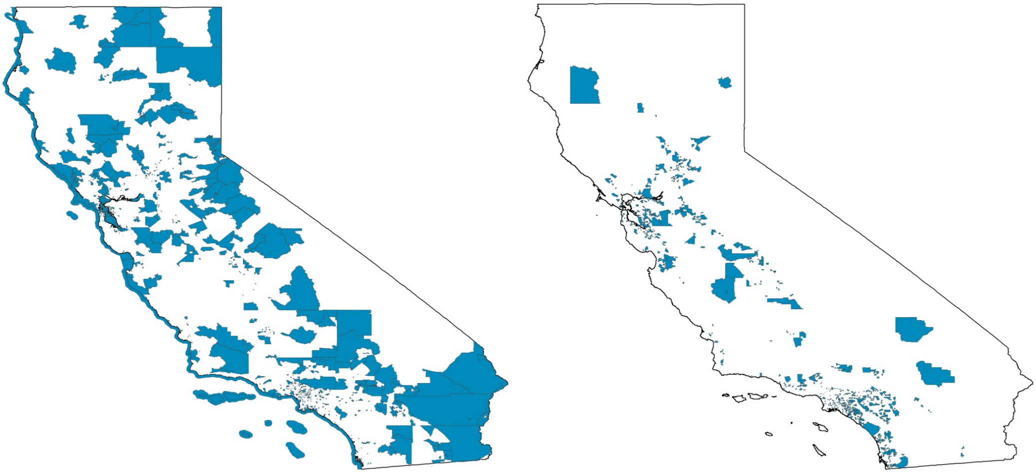
(a) 10th percentile



(b) 90th percentile

BACK

Census tracts at 10th and 90th percentile by population count



(a) 10th percentile

(b) 90th percentile

BACK