Driver Substitution Between Electric Vehicle Charging Stations

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Overview

Question: How does the distance between EV charging stations and charging price affect drivers substitution between stations?

Hypothesis: Distance and prices has less of an effect on EV charging substitution decisions than for gasoline drivers

Motivation: How stations compete spatially has implications for future placement of stations, entry decisions, and pricing.

Data: Transaction-level EV charging data from the Kansas City charging network

Empirical model/design: differences-in-differences, logit, poisson

Differences Between EV Charging and Gasoline

- Time required to charge EVs
  - L2 Chargers: 4-12 hours to charge a vehicle
  - L3 Chargers: 30-60 minutes to charge to 80% (less common)
- Home charging may be available to EV drivers
- Charging typically costs between 15-33 ¢/kwh

Why Should We Care About EV Charging Stations?

Charging stations are essential for EV adoption

- Y. Zhou and Li (2018)
- Springel (2017) and Li et al. (2017)

Growing number of EV chargers are built each year

- U.S. charging stations grew from only 541 stations in 2011 to more than 78,000 in 2019

Models Assume Driver Substitution Similar to Gasoline

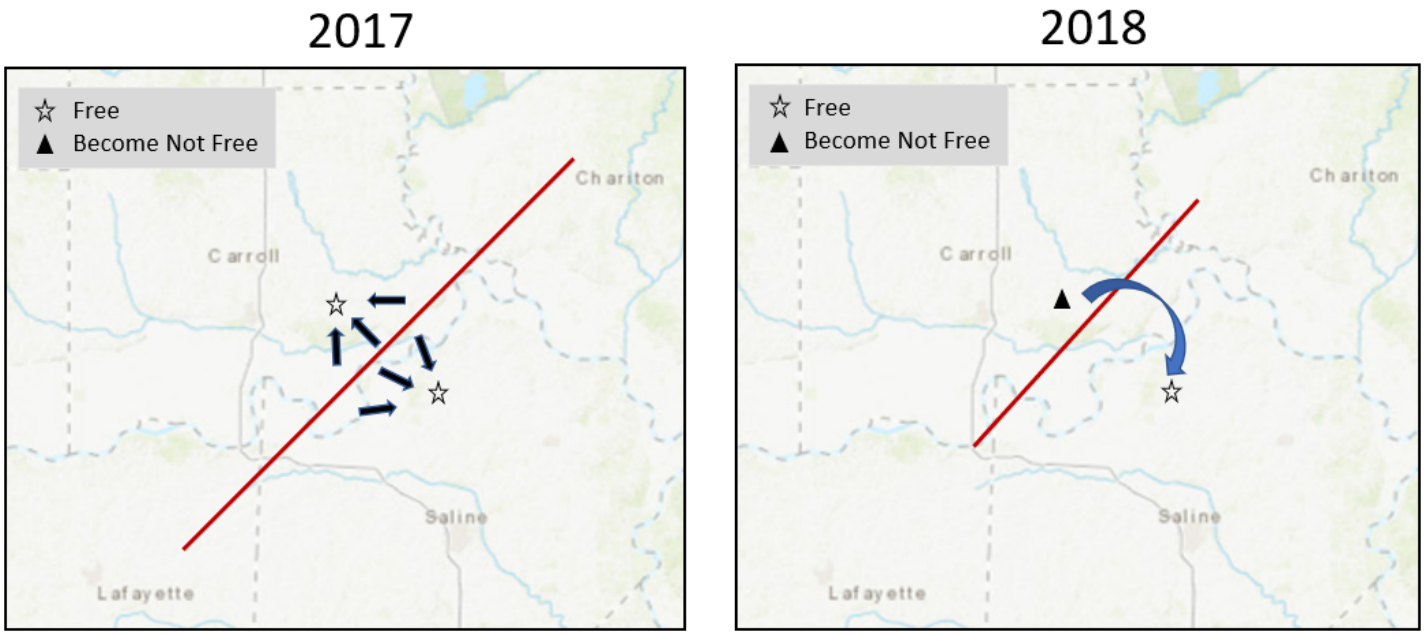
Engineering models and simulations of station placement

- He et al (2015)
- Zhang et al (2016)
- Lou et al (2017)
- Greene et al (2020)

Economic models of station entry

- Y. Zhou and Li (2018)

Common Expectation of Station Substitution

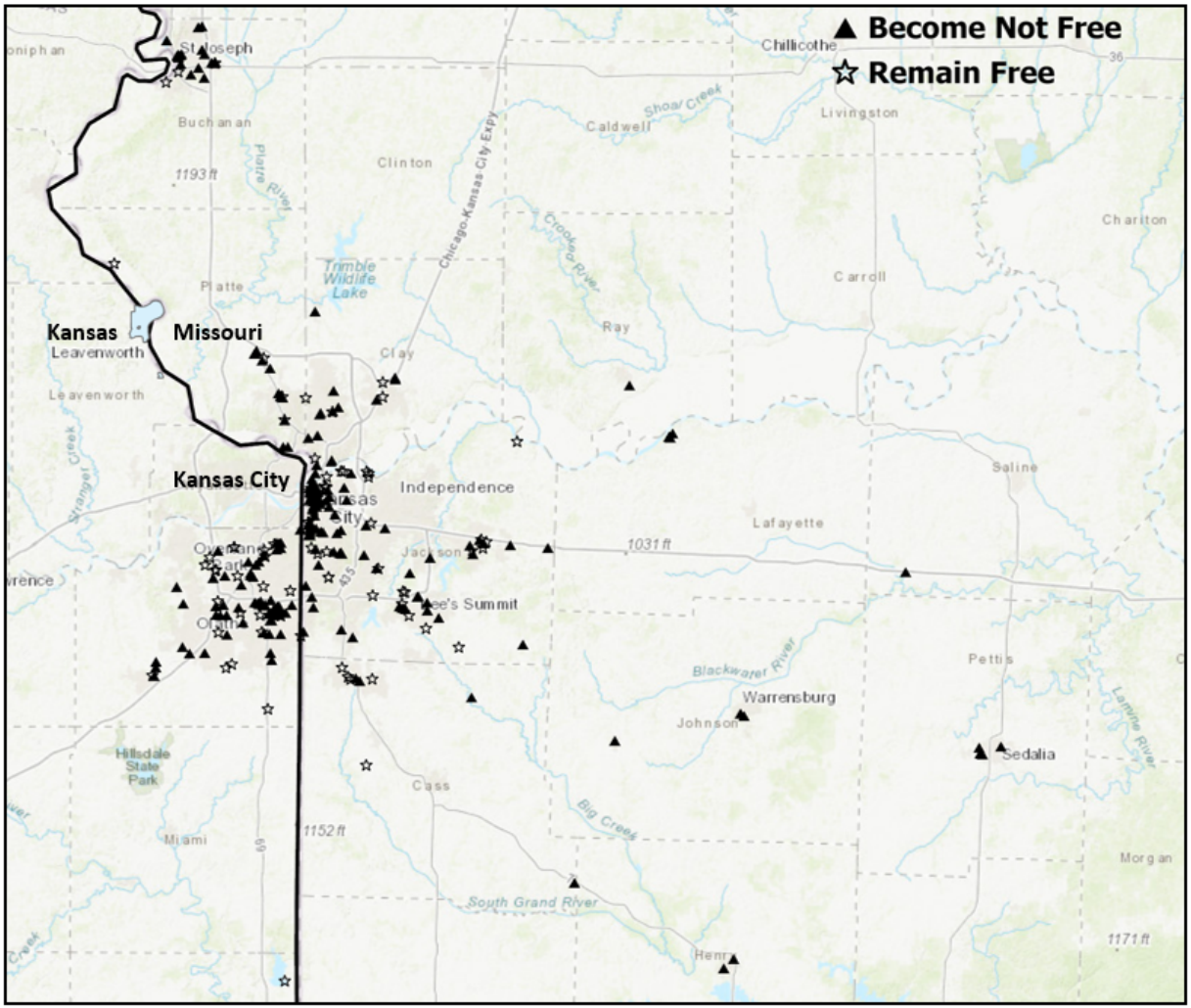


Previous models assume drivers move from stations that become not free to nearby free stations

Background of Evergy Charging Network

- Installed 284 charging locations in 2015 and 2016 (264 level 2 stations)
- Subsidized all charging until January 1, 2018
- 87 (30%) stations remained free in 2018
- 197 (70%) stations become not free in 2018
- Only include level 2 Stations in this analysis

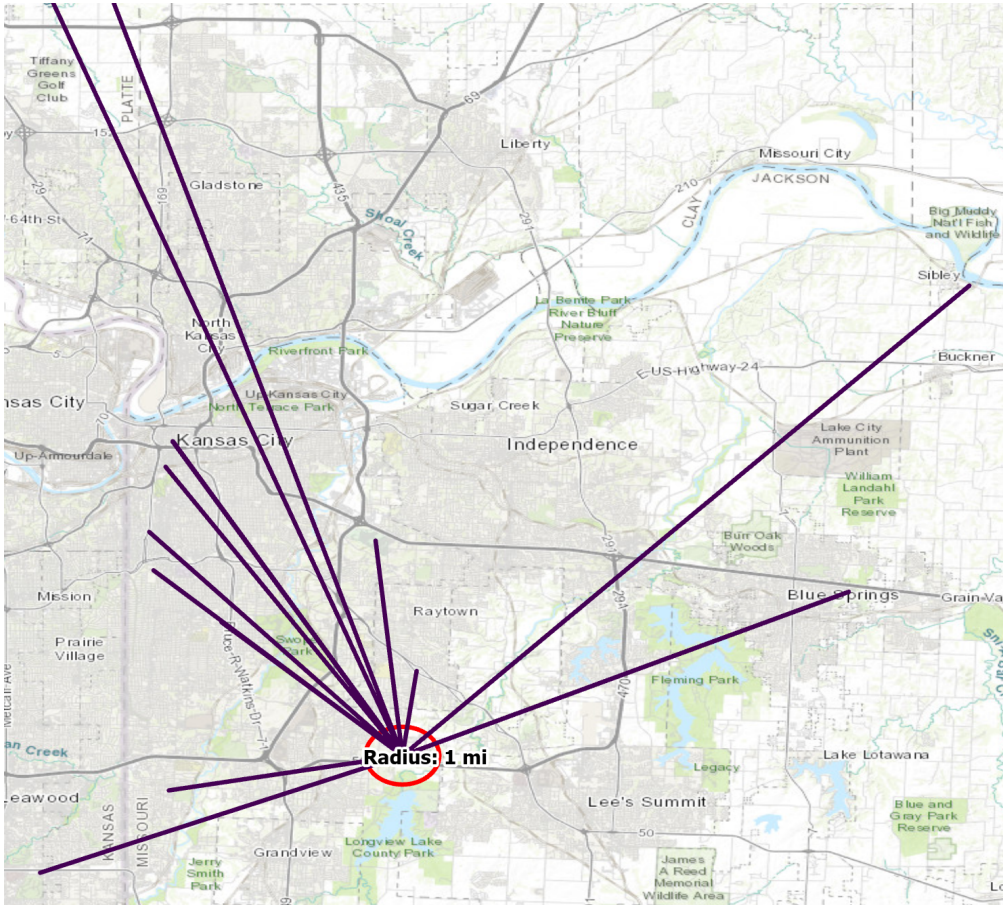
Kansas City Charging Network



Data

- 1386 drivers across both years
- Transaction data for every charging event includes: KWHs charged, price, driver ID, station ID, time, and date
- Transaction data allows me to observe how individual drivers substitute across stations after the subsidy ends

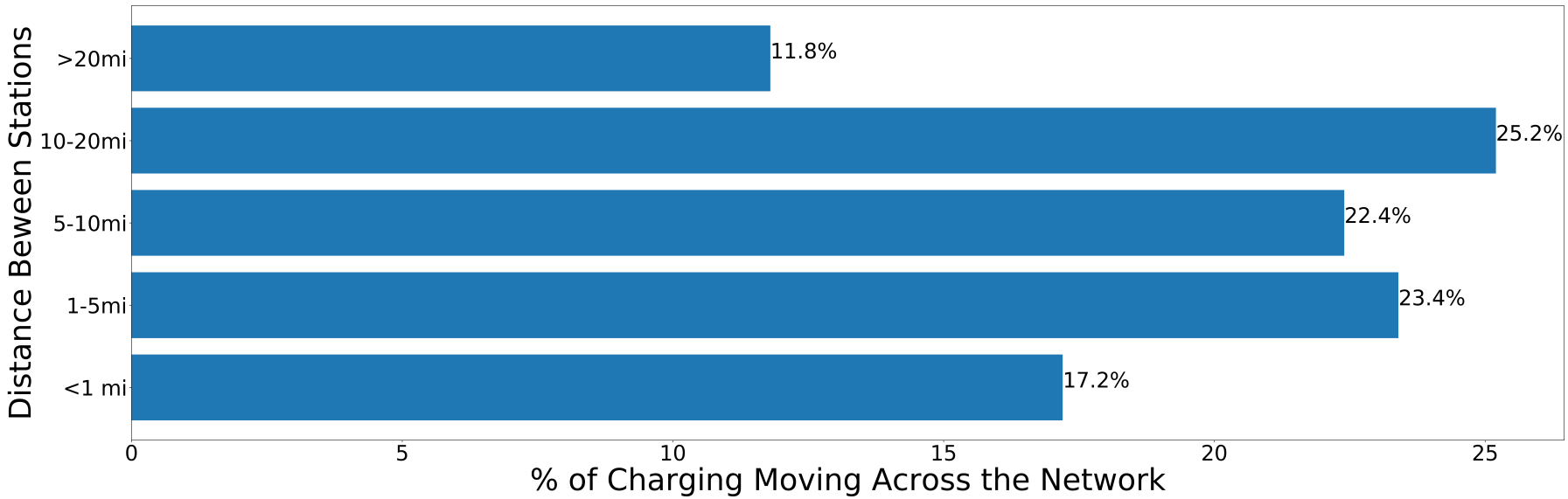
Example of Charging Movement Across Network



Aggregate Movement of Charging Across the Network

	Leave Network	Switch to L2 Free	Switch to L2 Not Free	Switch to L3
Begin to Charge (KWH)	176,225	16,047.3	14,767.6	3,761.4
%	83.6%	**7.0%**	**7.6%**	1.8%
Remain Free (KWH)	22,359.9	4,051.6	2,697.1	593.9
%	75.3%	13.6%	7.6%	2.0%

How Far Do Drivers Move?



82% of charging moves more than 1 mile

Estimation Approach

1. Station Analysis
   - Stations that become not free
   - Stations that remain free

2. Driver analysis
   - Logit analyze where drivers substitute
   - Poisson estimates how much drivers substitute to each station

Station Analysis: Station That Become Not Free

$$ln(Usage_{it}) = \alpha NotFree_{it} + \beta Density_i XNotFree_{it} + \gamma_i + \phi_t + \epsilon_{it}$$

- Usage: average per port KWH usage
- NotFree: indicates stations i is not free in time t
- Density: # of charging stations within 1 mile of station i
- γ: station fixed effects
- ϕ: month fixed effects

Estimates: Stations That Become Not Free

Dependent Variable:	ln(Per Port Usage (KWHs))			
	(1)	(2)	(3)	(4)
Variables				
Density 1mi	0.0020			
	(0.0045)			
Density 0.5mi		0.0077		
		(0.0100)		
Free Density 1mi			0.0050	
			(0.0153)	
Free Density 0.5mi				0.0023
				(0.0306)
NotFree	-0.7932***	-0.8011***	-0.7877***	-0.7810***
	(0.1261)	(0.1255)	(0.1247)	(0.1234)
Observations	3,120	3,120	3,120	3,120
R^2	0.83770	0.83776	0.83768	0.83767
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*				

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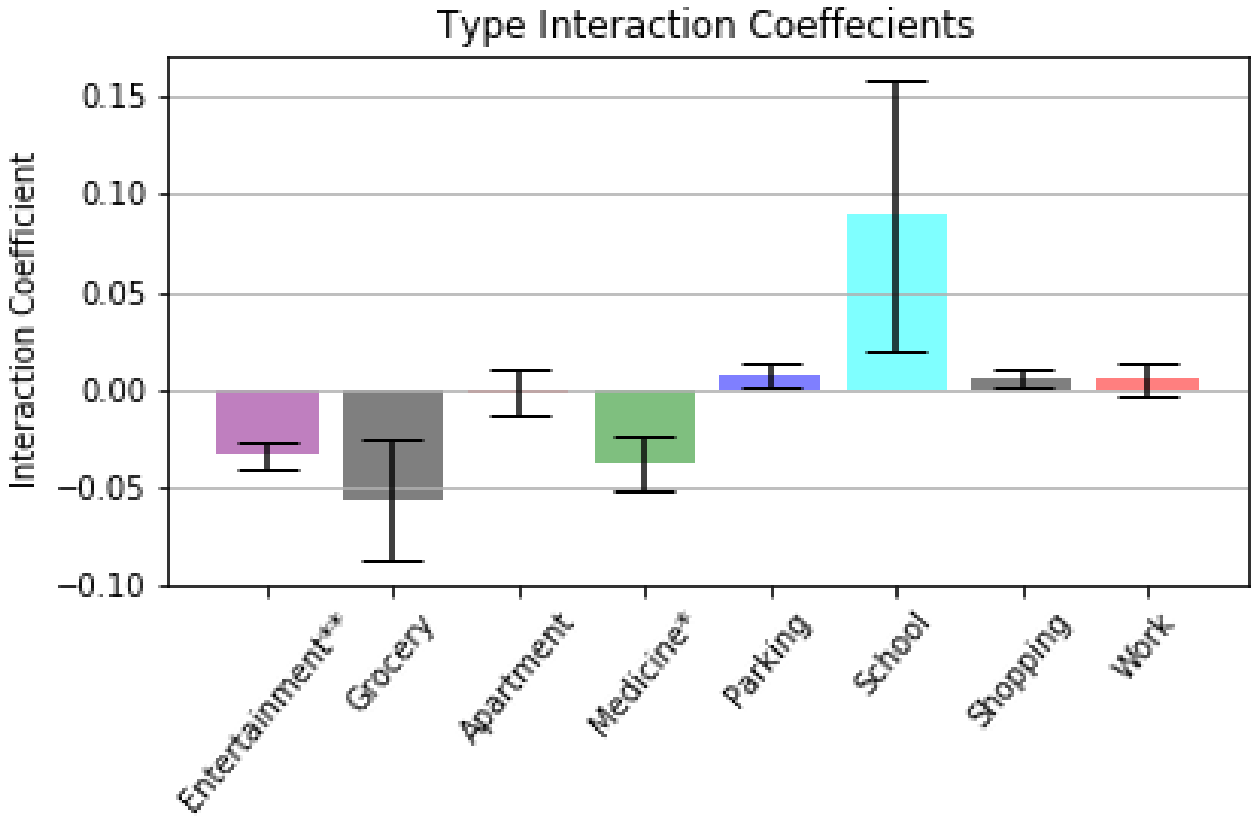
Estimates by Type of Business Near A Station



Station Analysis: Stations that Remain Free

$$Usage_{Fit} = Density_{NFi}X2018_t + \gamma_i + u_{it}$$

- Usage: average per port KWH usage
- $Density_{NF}$: # of stations that become not free within 1 mile of station i
- 2018: dummy variable that indicates the year is 2018
- γ: Station fixed effects
- ϕ: Month fixed effects

Estimates: Stations That Remain Free

Dependent Variable:	ln(Per Port Usage (KWHs))		
	All	<9mi from downtown	>19 miles from downtown
$Density_{NF}$ X 2018	0.0226**	0.0221*	0.0948
	(0.0102)	(0.0105)	(0.1263)
Observations	888	240	192
R^2	0.83491	0.80722	0.78397

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Driver Analysis: Logit

$$U_{ij} = \alpha p_j + \beta X_{ij} + \epsilon_{ij}$$

- p: price at station j after the subsidy ends
- X: station j characteristics for driver i
- Within 1 mile: indicates station j is within 1 mile of origin station
- Free: station j remains free
- Previously Visited: indicates driver charged at station j in 2017
- ϕ: driver fixed effects

Logit Estimates

Dependent Variable:	All Stations	Visited <9mi from downtown	>19 miles from downtown
Previously Visited	2.768***	2.357***	2.782***
	(0.1226)	(0.2346)	(0.2222)
Free	0.4467***	0.5224***	0.5851***
	(0.1142)	(0.1570)	(0.1640)
Within 1 mi	0.4583***	0.3799***	0.4657***
	(0.0555)	(0.1092)	(0.1304)
Observations	1,354,155	327,997	289,226

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Logit Estimates: Not Previously Visited Stations

Dependent Variable:		Visited	
Model:	All Stations	<9mi from downtown	>19 miles from downtown
Free	0.1644	0.1644	0.1644
	(0.1729)	(0.1729)	(0.1729)
Within 1 mi	0.5577***	0.5577***	0.5577***
	(0.0685)	(0.0685)	(0.0685)
Observations	1,138,669	1,138,669	1,138,669

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Driver Analysis: Poisson

$$\lambda_{ij} = exp(\alpha p_j + \beta X_{ij} + \epsilon_{ij})$$

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- X: station j characteristics for driver i
- Within 1 mile: indicates station j is within 1 mile of origin station
- Free: station j is remains free
- Previously visited: indicates driver charged at the station in 2017
- ϕ: driver fixed effects

Poisson Estimates

Model:	All Stations	<9mi from downtown	>19 miles from downtown
Previously Visited	3.420***	2.627***	2.843***
	(0.1528)	(0.2389)	(0.2752)
Free	0.5369***	0.5419***	0.6999***
	(0.0942)	(0.1594)	(0.1656)
Within 1 mi	0.6476***	0.5815***	0.9384***
	(0.0936)	(0.2178)	(0.2254)
Observations	1,354,155	309,566	273,043

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Conclusion

- Station density does not affect station usage
- Previous charging behavior has more of an effect than price or location on substitution
- Driver substitution may have implications for station location